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Design and Implementation of a Bottomfish Fishery-independent Survey in the Main Hawaiian Islands

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Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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Design and Implementation of a Bottomfish Fishery-independent Survey in the Main Hawaiian Islands

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Executive Summary

Commercial and recreational fishing are important to the economy and culture of Hawaii. The deep-slope bottomfish commercial fishery preferentially targets seven high value "Deep-7" species (i.e, six snappers and one grouper, hereafter referred to as bottomfish). The NOAA Pacific Islands Fisheries Science Center (PIFSC) Stock Assessment Program is responsible for regularly conducting assessments of bottomfish. The stock assessment process requires reliable time-series of catches, fishing effort and life history demographics to estimate stock abundance trends and evaluate sustainability benchmarks. Current bottomfish stock assessments that rely solely on fishery-dependent abundance indices may be biased (Ault et al., 2014). A series of workshops convened in 2001-2005 evaluated existing bottomfish stock assessment methodologies in the Pacific Islands Region (PIR; Mace et al., 2001; Ralston et al., 2004). Mace et al. (2001) noted that the greatest impediment to credible bottomfish stock assessments was the lack of accurate and precise input data. To improve abundance estimates, Ralston et al. (2004) recommended development of a fishery-independent survey using available "advanced technologies". A 2005 workshop on *Ecosystem Science and Management Planning* reiterated the pressing need for a design and implementation of population-level fishery-independent survey to obtain size-structured abundance data for bottomfish, and to aggressively pursue development of length-based assessment models.

This goal of this technical report was to improve stock assessments through optimal design and implementation of a bottomfish fishery-independent survey for the Deep-7 bottomfish complex in the main Hawaiian Islands (MHI) with three primary objectives:

1. Evaluate the most effective survey gears for obtaining species-specific spatial size-structured abundance metrics of the Hawaiian bottomfish stock;

2. Conduct quantitative gears intercalibration studies to determine the relative fishing power of the multiple gears to be used in the survey;

3. Detail the required methodologies for efficient conduct of a multi-gear fishery-independent survey of the MHI bottomfish stocks.

Six pilot survey missions were conducted in the MHI over the 2011–2015 timeframe. Two primary operation goals drove the experimental designs: (1) gear efficacy comparisons; and, 2) pilot sampling in an effort to determine the appropriate operational survey design.

The primary survey gears evaluated for the fishery-independent sampling survey were: (1) hook and line fishing; (2) stationary stereo-video camera platforms (BotCam); autonomous underwater vehicles using stereo-video cameras; and (4) active acoustics. Gear efficacy assessments were based on size-structured catches, relative fishing power and operational costs. A two-stage stratified random sampling design was chosen for the survey. Sampling gears were randomly allocated to primary sampling units (PSUs) stratified mapped at 500-m resolution by "habitat" classes that were combinations of the factors: substrate composition, bottom slope, and depth. Habitat classes were defined as: hardbottom, high slope (HBH); hardbottom, low slope (HBL);

and, softbottom, no slope (SBA). Each of these habitat classes were further divided into three depth ranges: 75–200; 200–300; and, 300–400 m. At least three of the four gear types were deployed on each mission, but due to logistical and contracting issues the full suite of four sampling gears was only deployed on two missions.

To compare the efficiency of each sampling gear in a comparative manner, it was necessary to first define a standard sampling method and sampling unit. For research fishing, a standard sample was defined as 30 minutes of active fishing effort within a PSU by one vessel using two bait types on separate rods with each line comprised of four 3/0 hooks. A standard BotCam sample was defined as a 15-minute deployment, which was reduced from an initial 45-minute drop. Reducing soak time greatly reduced analysis time and resulted in a 37% cost savings per sample. Due to limited resources for BotCam video analysis, PIFSC prioritized the analysis these data through a partnership with the University of Hawaii at Manoa. For the AUV, within each PSU three parallel 200 m transects separated by 25 m were run. For active acoustics 2-6 passes using a Simard EK60 were made within a particular PSU. With the possible exception of active acoustics, all gears appeared to detect bottomfish species, but to greatly differing degrees. Research fishing resulted in little bycatch of non-target species, BotCam and AUV mostly contained bottomfish, though some additional species were detected. Active acoustics were largely unreliable in discriminating bottomfish species. These gear performance analyses suggested that use of research fishing and BotCam were the most reliable to be used in the eventual MHI fishery-independent bottomfish survey.

For several primary bottomfish species, research fishing and BotCam indicated similar occurrence and relative abundance (CPUE) patterns. Mean occurrence and CPUE were generally higher in HBH and HBL habitats, as compared to SBA habitats, but greater in high slope as compared to low slope hardbottom habitats. CPUE variance was proportional to the mean. While there were minor variations between research fishing and BotCam, both methods indicated that Ehu and Onaga had higher CPUE at depths greater than 175 m, while the highest Opakapaka CPUE occurred at depths less than 175 m. Bottomfish exhibited a clear preference for certain baits. Onaga and Ehu CPUE were greatest when fish was used; whereas, Opakapaka CPUE was highest for squid. Mean occurrence was typically greater for research fishing, while mean fish seen (or caught for fishing) was greater higher for BotCam. Thus, overall relative fishing power was higher for BotCam as to research fishing. Research fishing cost per sample was about half of that for a 15-min BotCam sample.

We believe that most efficient design of the operation survey would stratify PSUs by depth and habitat. This stratification would include two depth intervals: 75–200 m; and, 200–400 m; and three habitat strata: hardbottom–high slope, hardbottom–low slope, and softbottom areas. These recommended stratifications effectively partition the variance of CPUE and would produce the most precise mean stock abundance estimates for the lowest cost.

Our results to date suggest that a multi-gear fishery-independent survey of Hawaii bottomfish is feasible and cost-effective. Research fishing and BotCam appear to be effective complimentary gears in sampling bottomfish assemblages and show striking similarity in species-specific length compositions as well as spatial distribution patterns across depths and habitats. However, these gears cannot be deployed over the full range of the bottomfish stock complex. Research fishing

can be employed across all depth-habitat strata, but, because it is an extractive technology, cannot be used within marine protected areas. On the other hand, BotCam can be employed in all geographic areas, but cannot sample in depths greater than 300 meters due to ambient light restrictions. Thus both gear types should be used in the operational fishery-independent survey. Preliminary results suggest that an operational fishery-independent survey for MHI bottomfish could be accomplished using only cooperative research vessels. Due to the greater distance between sampling locations in an operational MHI survey, we suggest the use at least four cooperative research vessels within each of four MHI zones during a fall and possibly a spring survey sampling window of 30–60 days.

CONTENTS

INTRODUCTION

Commercial fishing for deep-slope bottomfish has been an important component of the Hawaiian economy and culture for over a century (Haight et al., 1993). The bottomfish fishery preferentially targets the "Deep-7" (i.e., six snappers and one grouper species), primarily using hook and line gears (Brodziak et al., 2011; Fig. 1). In 2012, there were 458 State of Hawaii Commercial Marine License (CML) holders that reported landings of bottomfish in the main Hawaiian Islands (MHI). The commercial fleet uses vessels ranging from 4.5 to 21 m in length (WPRFMC, 2010), and 2012 commercial harvests totaled 2315,000 lbs with an ex-vessel value of $1.6 million USD (Brodziak et al., 2014).

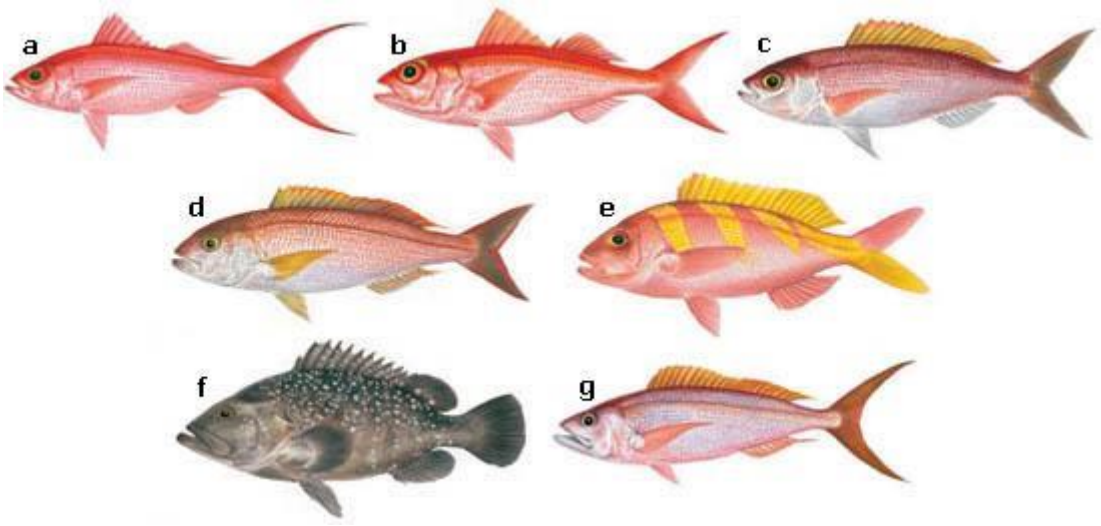

Figure 1.--The main Hawaiian Islands "Deep-7" bottomfish complex: (A) Onaga (Etelis coruscans), (B) Ehu (Etelis carbunculus), (C) Kalekale (Pristipomoides sieboldii), (D) Opakapaka (Pristipomoides filamentosus), (E) Gindai (Pristipomoides zonatus), (F) Hapu'upu'u (Hyporthodus quernus), and (G) Lehi (Aphareus rutilans). Artwork by Les Hata (Hawaii DAR/DLNR).

The NOAA Pacific Islands Fisheries Science Center's Fisheries Research and Management Division is responsible for conducting stock assessments of bottomfish every three years. These assessments are used by the Western Pacific Regional Fishery Management Council (WPRFMC) to determine sustainability status of the resource and for setting annual catch limits for fishery (i.e., combined commercial, recreational and subsistence users). Once an annual catch limit is reached (non-commercial fishing accounts for a very small portion of the reported catch), the fishery is closed.

The stock assessment process requires reliable time-series of catches, fishing effort and life history demographics to estimate stock abundance trends and evaluate sustainability

benchmarks. Past assessments have relied on commercial catch and effort data that has been of varying quality. Data derived from commercial catch reports can be biased due to imposed size and catch limits, variable gear types, and market forces (Maunder and Punt, 2004). To date, Hawaii Deep-7 bottomfish stocks have been assessed as a holistic complex, creating substantial uncertainty in species-specific abundances and population dynamics.

The commercial fleet utilizes a variety of fishing methods to capture and sample the stock, many of which can yield CPUE statistics, which may not be proportional to the true abundance of the stock (Maunder and Punt, 2004). Additionally, while current assessments have taken into account short and long-term temporal effects (yearly and seasonal) as well as the effects of geography (reporting grids specified by the Hawaii Division of Aquatic Resources (HDAR)) and fisher skill when standardizing CPUE (Brodziak et al., 2014), these assessments have utilized only fishery-dependent data and have treated the Deep-7 species as a homogenous stock complex, rather than as individual species.

A series of workshops convened in 2001–2005 evaluated existing bottomfish stock assessment methodologies in the Pacific Islands Region (PIR; Mace et al., 2001; Ralston et al., 2004). Mace et al. (2001) noted that the greatest impediment to credible bottomfish stock assessments was the lack of accurate and precise input data. To improve abundance estimates, Ralston et al. (2004) recommended development of a fishery-independent survey using available "advanced technologies". A 2005 workshop on *Ecosystem Science and Management Planning* reiterated the pressing need for the design and implementation of a population-level, fishery-independent survey to obtain size-structured abundance data for bottomfish, and to aggressively pursue development of length-based assessment models.

The goal of this technical report is to improve stock assessments through optimal design and implementation of a fishery-independent survey for the Deep-7 bottomfish complex in the main Hawaiian Islands (MHI) with three primary objectives:

1. Evaluate the most effective survey gears for obtaining species-specific spatial size-structured abundance metrics of the Hawaiian bottomfish stock;

2. Conduct quantitative gears inter-calibration studies to determine the relative fishing power of the multiple gears to be used in the survey;

3. Detail the required methodologies for efficient conduct of a multi-gear fishery-independent survey of the MHI bottomfish stocks.

METHODS

This study considered several fishery-independent sampling methods: cooperative-research hook and line fishing (research fishing); stationary stereo-video camera platform (BotCam); autonomous underwater vehicle with stereo-video cameras; and, active acoustics (Simrad EK60). Gears were chosen based on their current use within and applicability to the fishery (research

fishing), their ability to provide species-level size-structured abundance estimates (research fishing, camera platforms), or their ability to sample both day and night covering a large portion of the water column over a large spatial area (research fishing, EK60). EK60 active acoustics and the SeaBED AUV were determined to not yet be ready for operational use and they will not be discussed further. Some preliminary details on these gears are shown in Appendices 1 and 2.

Field operations have been carried out from 2011 to 2014 in three phases (Table 1). Phase 1 concentrated on sampling methods development and standardization. Phase 2 focused on calibration of the gears developed during Phase 1. Phase 3 further refined sampling methods and conducted a pilot study for transition to an operational multi-gear fishery-independent survey. Overall, six survey missions of 10 - 15 days each were completed (Table 1) utilizing three distinct sampling designs, one for each experimental phase (Figs. 2–4, respectively).

Table 1.--Survey missions with experimental design for each mission and survey gears fielded during each mission. PSU reflects the number of primary sampling units surveyed by each gear during each mission. The BotCam and EK60 gears were each fielded by a single vessel while research fisher operations were conducted by 3 vessels, allowing for a greater number of PSUs to be sampled using that gear.

Phase	Year	Survey Period	Mission ID	Research Objective	Experimental Design	Survey Gears Fielded	PSU
1	2011	2/25 - 3/8	SE1102	pilot study	Stratification within Survey Boxes (Figure 2.a)	BotCam	84
						EK60 active acoustics	108
						Research fishing	70
1	2011	9/18 - 9/27	SE1107	gear comparison & strata effects	Stratification within Survey Boxes (Figure 2.a)	BotCam	79
						SeaBed AUV	70
						EK60 active acoustics	84
1	2012	9/20 - 10/3	SE1208	gear comparison & strata effects	Stratification within Survey Boxes (Figure 2.a)	BotCam	89
						EK60 active acoustics	60
						Research fishing	146
2	2013	4/18 - 4/30	SE1302	fishing power comparisons	Target PSUs (Figure 2.b)	BotCam	144
						SeaBED AUV	10
						EK60 active acoustics	30
						Research fishing	151
2	2013	7/30 - 8/11	SE1306	fishing power comparisons	Target PSUs (Figure 2.b)	BotCam	62
						SeaBED AUV	12
						EK60 active acoustics	10
						Research fishing	125
3	2014	4/5 - 4/19	SE1402	pilot multi-gear fishery-independent survey	Stratified-Random (Figure 2.c)	BotCam	73
						SeaBED AUV	22
						Research fishing	197

Study Area and Sample Units

Field surveys were conducted during the spring and fall in a study area between the islands of Maui, Lanai, and Molokai (inset, Fig. 2). That area–along with the Penguin Bank area–is generally regarded as a center of the MHI deep-slope bottomfish fishery (Parke, 2007). The survey domain was gridded at 500 m and each 500 × 500 m grid cell constituted a primary sampling unit (PSU). The size of the PSU was chosen to accommodate all four gears. This PSU size ensured that research fishing operations could easily be conducted while remaining within

the PSU especially at times of high wind or current, and was also sufficiently large to allow for individual transects across the cell by both the EK60 and AUV. For BotCam, while the deployment position of a camera lander can easily be determined prior to deployment, the system can drift horizontally with the current during its descent to the sea floor. From previous experience (Dr. Jeffrey Drazen, pers. comm.) it was reasonable to expect that a camera lander would remain within 50 m of the target center point of the 500 × 500 m PSU during its descent, even during times of high current, and also not attract fish from adjacent grid cells during sampling period of up to 45 minutes.

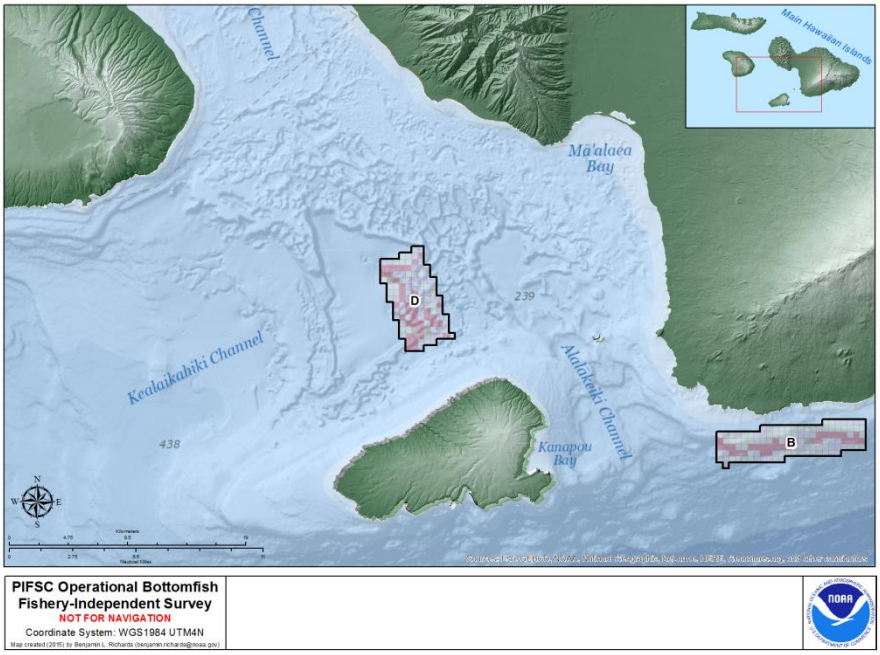

Figure 2.--Survey domain for the quantitative comparison among advanced fishery-independent sampling methods showing Phase 1 sampling. The survey area was gridded at 500 m and classified by substrate, composition (hard, soft), benthic slope (high, low), and depth (target range (75–400 m). In 2011–2012, sampling was primarily constrained to PSUs within each of 2 survey boxes (B,D), each of which contained a wide range of depth and habitat types.

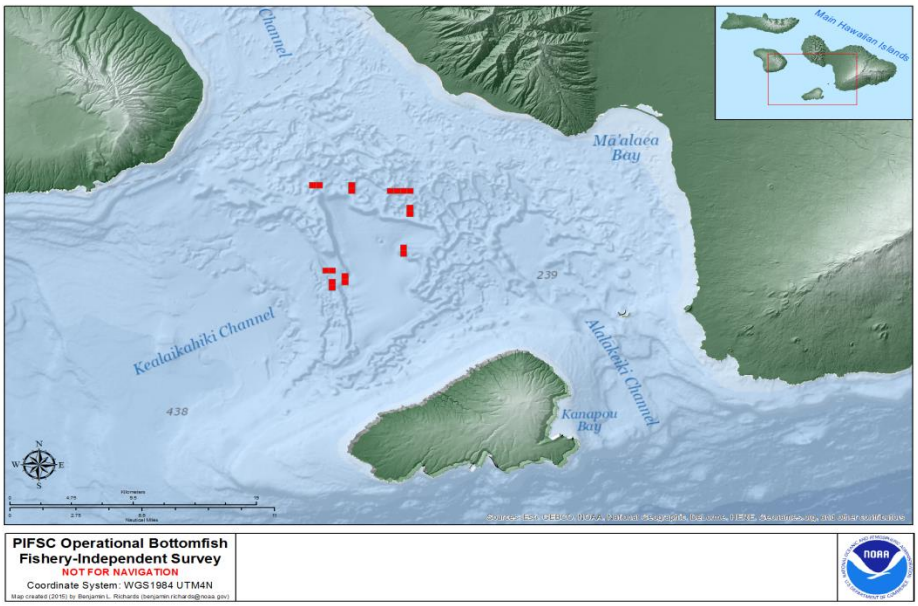

Figure 3.--Survey domain for the quantitative comparison among advanced fishery-independent sampling methods showing Phase 2 sampling. PSUs which had shown high bottomfish occurrence in Phase 1 were intensively resampled to develop gear-specific calibration factors.

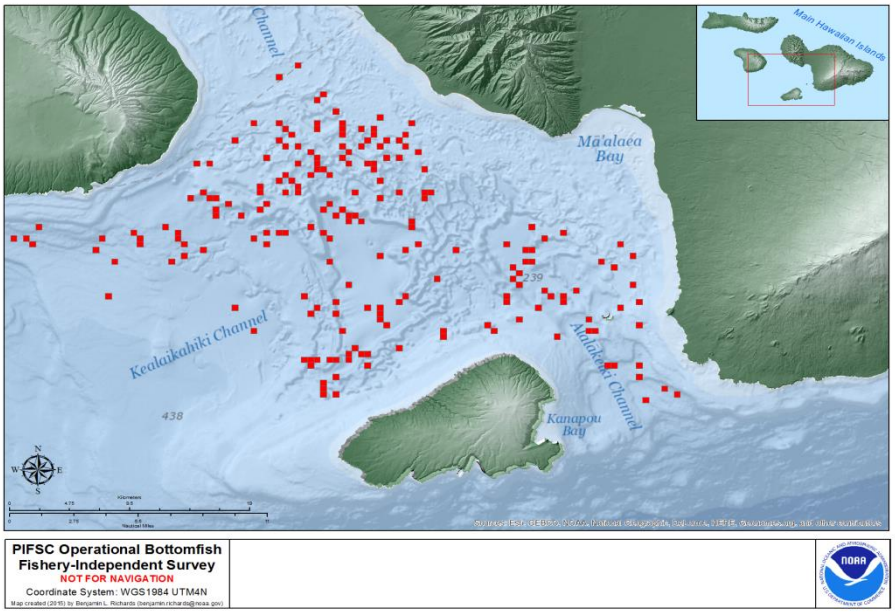

Figure 4.--Survey domain for the quantitative comparison among advanced fishery-independent sampling methods showing Phase 3 sampling. PSUs (500 × 500 m) were stratified by substrate composition (hard, soft), benthic slope (high, low), and depth (75–200 m; 200–300 m; 300–400 m). Gears were allocated in a stratified-random design to PSUs across the full study area within the Maui Nui region.

Depth and habitat characteristics of each PSU were determined from 20-m-resolution multibeam bathymetric and backscatter data. The depth of each PSU was estimated as the average depth of the 20-m pixels within each PSU. High slope for a 20m pixel was defined as slope greater than 20°. Hard or soft substrate for a 20-m pixel was determined from backscatter data. Slope and substrate pixels were used to designate habitat type for a PSU of 500 × 500 m following a hierarchical classification scheme (Table 2).

Table 2.--Hierarchical habitat classification scheme for each 500 m^2 primary sampling unit (PSU) based on 20 m per pixel resolution multi-beam products. HBH = Hardbottom, high slope; HB_L = Hardbottom, low slope; SB_H: Softbottom, high slope; SB_L = Softbottom, low slope; UN_U = Unclassified. If any if any HB_H pixels were present within the PSU, the PSU was classified as HB_H. If no HB_H pixels were present but there was presence of either HB_L or SB_H, the classification was based on proportion of pixels within the PSU of HB_L and SB_H. The PSU was classified as SB_L if only this type was present.

Criterion	Habitat Designation
Area of HB_H > 0	HB_H
HB_H=0, HB _L > SB_H	HB_L
HB_H=0, SB_H > HB_L	SB_H
HB_H=0, HB_L=0, SB_H=0, SB_L>0	SB_L
HB_H=0, HB_L=0, SB_H=0, SB_L=0	UN_U

Phase 1: Sampling Methods Development

Research Fishing

The Hawaii bottomfish fishery is generally conducted by fishermen on small vessels (20–40 ft) using manual or hydraulic handline fishing gear (Fig. 5). Research fishing was conducted by the Pacific Islands Fisheries Group (PIFG) operating within a sampling design developed in cooperation with scientists from PIFSC. To ensure that the data collected in this study were comparable with fishery-dependent data, each vessel conducted fishing operations using a standard protocol developed by PIFSC researchers, vessel captains, and observers, which was designed, to the extent possible, to mimic a commonly used commercial fishing method. Local commercial bottomfishing vessels, captains, and fishing observers were hired to ensure that this fishing method remained similar to one style of fishing widely used by the local fishing community.

Each day within a survey mission (Table 1), each of three PIFG vessels was randomly assigned to PSUs within the given survey area. A standard sampling unit for research fishing was defined as 30 minutes of active fishing effort within a PSU by one vessel with each of two bait types on separate lines. One line was baited with squid while the other was baited with anchovy or a similar fish (e.g. aku, kawakawa, opelu). Hooks were standardized to the size equivalent of a #10 Mustad circle hook, Maruto BKN #22, Eagle Claw EC-10 or similar. Each vessel used a small

palu or chum bag that was filled with ~1 kg of a 50/50 mixture of ground squid and the aforementioned fish bait. The operative assumption was that, with standardization of methodology among the participating vessels, differences in catch rates (CPUE) from one area to another reflect differences in the resident fish assemblage rather than differences in fishing method among vessels.

Figure 5.--A cooperative research fishing vessel contracted by the Pacific Islands Fisheries Group for this study.

Prior to fishing a PSU, vessels were allowed to use their onboard acoustic fishfinders to search for aggregations within the PSU. This is typical of how many bottom fishermen locate fish during normal fishing operations. If fish aggregations were not found using the fishfinder, fishermen would look for favorable bottom topography. The standard survey period was defined as the interval from time the lines entered the water to the time they left the bottom upon retrieval 30 minutes later. Haul-back time did not count towards the 30-minute survey time. For each PSU, observers recorded the date, vessel, survey start/end time/position, the number of lines being fished, and the type of bait and palu being used. For each fish caught, the observer on the vessel recorded the species name and fork length. Logsheet data were transcribed into spreadsheet format and analyzed to determine how various factors affected the CPUE and for comparison against other gears.

In-situ stationary stereo-video camera platforms are increasingly being used by marine scientists to non-extractively generate high-resolution, species-specific, size-structured abundance estimates (Cappo et al., 2006). BotCam (Fig. 6) (Merritt, 2005; Merritt, 2011) is a fully autonomous stationary stereo-video camera system that has been effectively used to collect fishery-independent species-specific size-structured abundance data on bottomfish in the main Hawaiian Islands (Moore et al., 2013; Sackett et al., 2014). The system consists of two low-light video cameras (Monochrome Navigator, Remote Ocean Systems, San Diego, CA) with an 80° diagonal field of view that can image targets in ambient light to a depth of 300 meters in

BotCam

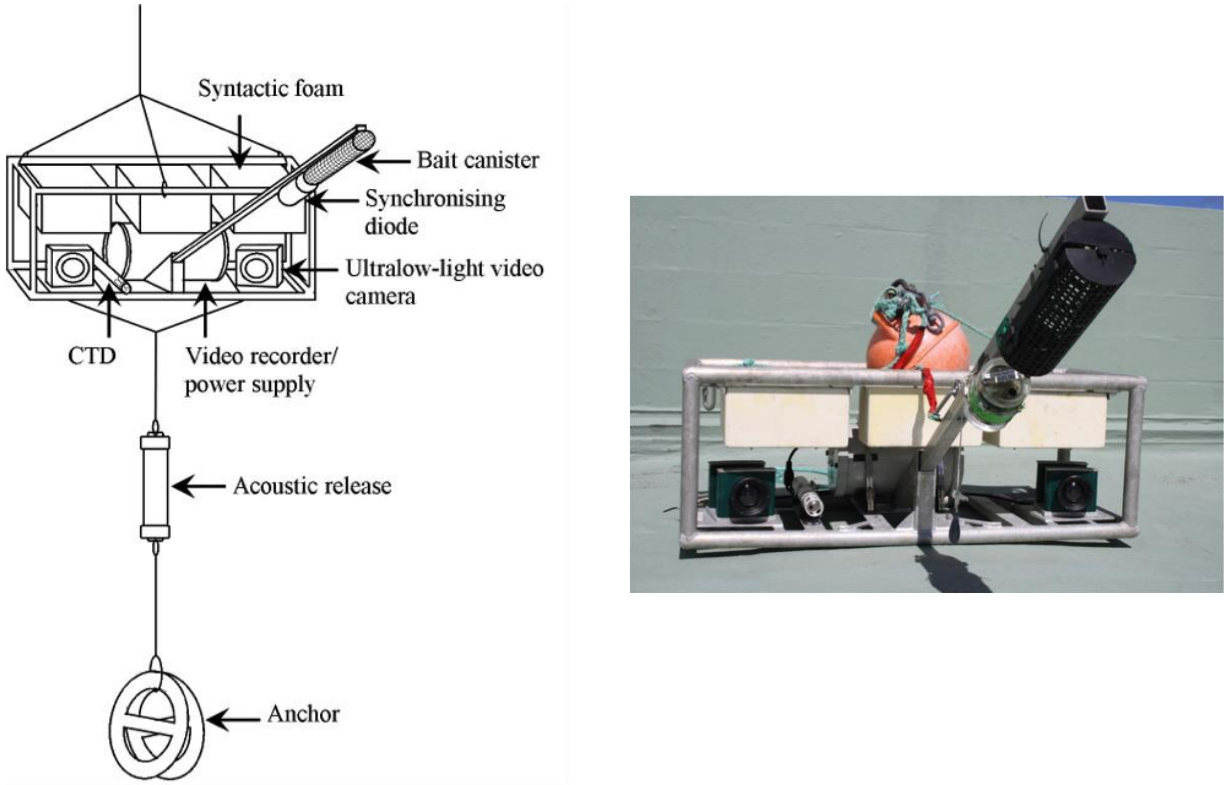

Figure 6.--A BotCam stationary stereo-video camera system.

Hawaiian waters. Video data are recorded to a digital video recorder (XM-DVR, DataToys, Mequon, WI). BotCam also employs a temperature and pressure recorder (SBE39TP, Seabird Electronics Inc., Bellevue, WA), a custom-built battery pack (The Sexton Company, Salem, OR), and syntactic foam blocks or trawl floats for positive buoyancy (Flotation Technologies, Biddeford, ME). The aluminum frame (1.2 m wide × 0.5 m deep × 0.45 m tall) is designed to protect the cameras and maintain fixed camera positions and also allows for the attachment of oceanographic instruments such as current meters, temperature and depth recorders, and hydrophones. An extension arm is used to carry both a stereo-video synchronizing (SVS) device and bait canister. The SVS, a grid of light emitting diodes (LED) that flash in rapid succession, allows the video stream from the two cameras to be synchronized to within $1/30^{th}$ of a second (one video frame) for accurate stereo-video measurements. The LEDs flash at 30 Hz for 1 second every minute; no reaction to the lights has been observed with any of the target species. The bait used in this study is a frozen 1 kg standard 1:1 mixture of fish (anchovies or sardines) and squid, ground to approximately 1 cm grain size, the same as that used in research fishing operations.

The system is moored to the bottom using an anchor weight (45–75 kg steel anchor chain links) attached to an acoustic release or shear pin and anchor line. BotCam is designed to float approximately three meters above the seafloor and to record video by pointing horizontally

down-current with a downward angle of 15° and a diagonal field of view of 80°. This configuration was chosen as the target species are known to school in the water column several meters above the bottom and higher and are known to favor steep and rocky slopes (Ralston and Polovina, 1982; Haight et al., 1993).

Within each survey mission (Table 1), BotCam units were randomly allocated to PSUs. During the first three missions, a single BotCam unit was allocated to each PSU and soak time was 45 minutes. Starting with the fourth mission (SE1302), soak time was reduced to 15 minutes based on analysis of data from the first 3 missions (discussed later in this document) and 2–3 replicate BotCam units were assigned to each PSU. Resulting stereo-video sequences were analyzed using the MaxN method to estimate size-structured abundance for each bottomfish species by a standard pool of analysts using stereo-photogrammetric software (EventMeasure, vers. 3.33 [SeaGIS Pty Ltd, Victoria, Australia]) (Fig. 7). MaxN is a commonly used (Ellis and DeMartini, 1995; Priede et al., 1996; Willis et al., 2000; Cappo et al., 2003; Gledhill et al., 2005; Merritt et al., 2011; Misa et al., 2013) conservative estimator of abundance that ensures that individuals are not recounted as they repeatedly leave and re-enter the frame. MaxN has also been found to correlate well with the traditional CPUE parameter used in fishing surveys for bottomfish (Ellis and DeMartini, 1995) and other species (Willis et al., 2000; Stoner et al., 2008). For the first three missions, MaxN was calculated for both the full 45-minute soak time as well for just the first 15 minutes. From SE1302 on, MaxN was calculated for the 15-minute soak time. This allowed us to compare soak times of 45 and 15 minutes and also provided a standard 15-minute MaxN data set from all missions.

The visual area sampled by BotCam varies with water quality, surface wave action, and degree of ambient light. Based on estimates by Moore et al. (2013), BotCam visual sampling area within the 100–300 m depth range in the main Hawaiian Islands ranged from 4 to 416 m^2 given minimum and maximum view distances of 2–10 m from the cameras. In their study, measured fish averaged 1.9 ± 0. 98 m from the cameras, with a maximum distance of 8.2 m.

Lengths of fish were taken at the time of MaxN or when the most measurable fish were present in the field of view. For each fish, the mean of 5 replicate measurements was computed to estimate fork length (FL). Measurements were accepted only if the root mean-square (RMS) error was < 10 mm and the RMS-to-FL ratio was < 10%. In addition, the substrate type was classified visually as to slope, bottom hardness, and general substrate type (rock outcrop, boulders, sand, etc.).

To evaluate optimal BotCam soak-time for this project, data from Misa et al. (in review) were used in addition to data from experiments SE1102, SE1107, and SE1208. Misa et al. (in review) used 1504 BotCam deployments with a 45-minute soak time in the main Hawaiian Islands and calculated MaxN values for time blocks that increased from 5 to 45 minutes (e.g. 0–5 minutes, 0–10 minutes, 0–15 minutes, etc). Misa et al. were able to determine cutoff periods during which MaxN occurred for the majority of deployments.

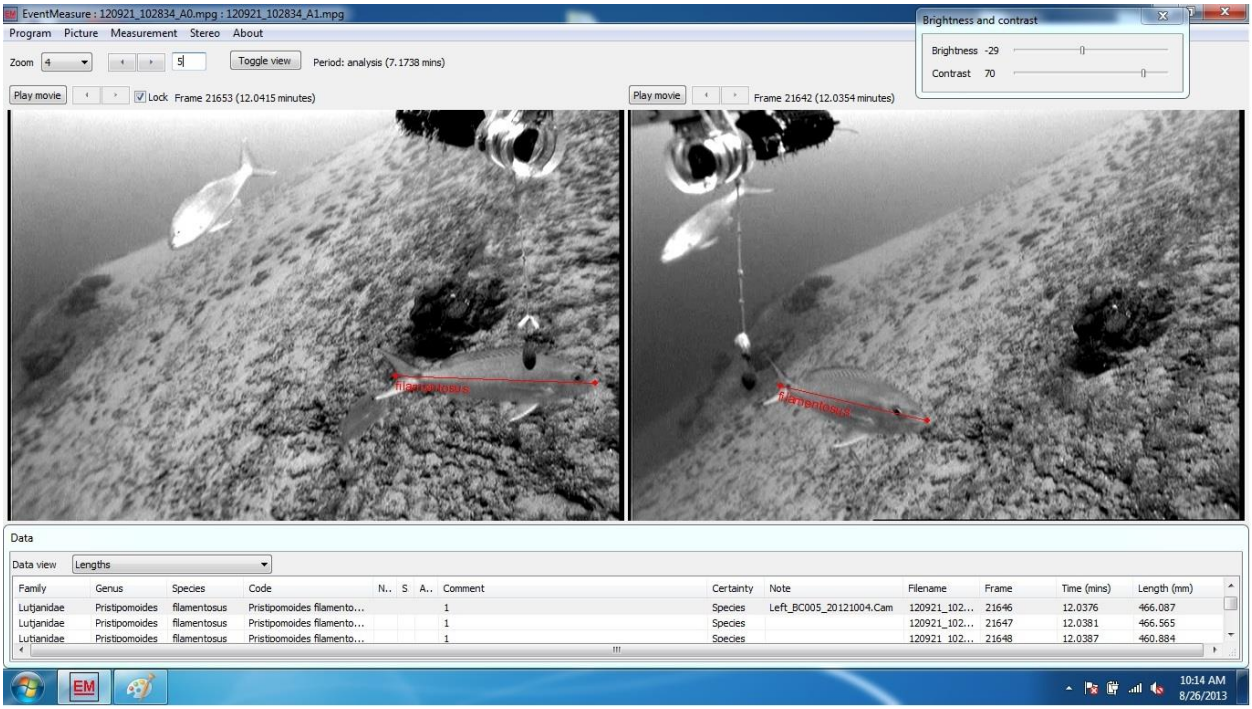

Figure 7.--A screen grab example from the SeaGIS EventMeasure™ desktop software package showing measurement of individual fishes.

Study Design

During Phase 1, sampling was constrained to PSUs within delineated survey boxes (subsets of the overall study area), each of which contained a wide range of depths and habitat types (Fig. 2). This facilitated co-sampling of PSUs by the various sampling gears within the limited 10–15 day time period of a given mission. A general space blocking scheme according to habitat class and depth was employed for missions SE1102, SE1107, and SE1208. Target PSUs were randomly selected within each space block for sampling by all gears.

Gear Comparisons

Data from Phase 1 missions were used to compare the research fishing and BotCam gears with respect to species catch and length compositions, and species abundance patterns by habitat and depth. Evaluation of the species composition of fishes captured by research fishing or observed by BotCam examined the percentage of Deep-7 bottomfish species vs. other species groups. Statistical analysis of differences in species length frequency between research fishing and BotCam were carried out using Kolmogorov-Smirnov tests.

Species abundance patterns were evaluated to understand the potential utility of using depth and habitat as stratification variables for a fishery-independent survey of bottomfish. The goal of stratification is to delineate the sample survey frame (i.e., the grid cell map) into sub-regions or strata with low, moderate, and high variance of CPUE. Since mean and variance of CPUE are usually highly correlated for reef-fishes (Smith et al., 2011), analyzing differences in mean

CPUE provides insights into differences in variance of CPUE among potential strata. Several arrangements of habitat and depth strata were evaluated using standard nonparametric tests (Mann-Whitney, Kruskal-Wallis, Conover) for differences in means and variances of CPUE for research fishing and BotCam gears. Nonparametric tests were used due to the highly skewed, non-normal distributions of CPUE observations for Deep-7 species for both gears.

Phase 2: Gear Calibration Experiments

Relative Fishing Power

Standardization of abundance indices between the research fishing and BotCam gears was carried out following the 'fishing power' method, which is based on fundamental principles of population dynamics theory (Beverton and Holt, 1957; Ricker, 1975). This approach was originally conceived by Gulland (1956) and Beverton and Holt (1956), and then formalized statistically by Robson (1966). Catch C in number of animals is related to average population abundance $\bar{N}$ in a specified time interval by

$$C = F\bar{N} = qf\bar{N} \tag{1}$$

where F is the instantaneous rate of fishing mortality, defined as the product of nominal fishing effort f and catchability coefficient q, the fraction of the stock removed per unit of nominal fishing effort. Catch-per-unit-effort (CPUE), a relative index of abundance, is given by

$$C/f = q\bar{N} \tag{2}$$

Catchability q may differ substantially among gears or sampling methods, but is often very difficult to estimate in practice; in addition, nominal effort f may be measured in different units for different gears, e.g., angler-hours, trap soak-hours, trip-days, etc.

The fishing power method estimates the relative catchability among different gears operating on the same unit stock. For two gears, CPUEs for gear 1 $\frac{C_1}{f_1} = q_1\bar{N}$ and gear 2 $\frac{C_2}{f_2} = q_2\bar{N}$ can be used to express the fishing power λ, or relative catchability, of one gear in terms of the other,

$$\frac{\frac{C_1}{f_1}}{\frac{C_{2=S}}{f_{2=S}}} = \frac{q_1}{q_{2=S}} = \lambda_1 \tag{3}$$

In this case gear 2 is designated as the 'standard' gear, and the fishing power λ can be multiplied by the effort of gear 1 to express the CPUE of gear 1 in terms of CPUE of the standard gear,

$$\frac{C_1}{f_1\lambda_1} = \frac{C_S}{f_S} \tag{4}$$

These principles also apply to abundance indices from fishery-independent surveys, whether they employ common capture gears such as trawls, traps, or seines, or whether they utilize non-extractive methods such as diver visual transects measuring fish density, the number of individuals observed (i.e., *C*) per unit area searched (i.e., *f*).

Fishing power models usually ascribe variation in CPUE to two main factors: (1) the times and locations of sampling effort, and (2) the type of sampling gears (or vessels) employed. Following Robson (1966), CPUE for time-location *i* and gear *j* can be estimated by a two-way analysis of variance (ANOVA) model of the form

$$CPUE_{ij} = \alpha + b_i + g_j + \varepsilon_{ij} \quad (5)$$

where α is a constant, b_i is a time-location coefficient, g_j is a gear coefficient, and ε_{ij} is an additive error term. The main assumption is that, for a given species or species life stage, the capture efficiency g_j is constant for each gear *j*. Our principal focus is obtaining accurate and precise estimates of gear parameters g_j in Equation 5. The coefficients b_i are included in Equation 5 to control for temporal and spatial variation in CPUE. The model-predicted CPUE for gear *j* is estimated by

$$\mathrm{CPUE}_j = \alpha + g_j \quad (6)$$

Following Equation 3, fishing power for gear *j* is estimated as the ratio of the model-predicted CPUE for gear *j* to the model-predicted CPUE of a standard gear (i.e., *j* = S),

$$\lambda_j = CPUE_j / CPUE_s \quad (7)$$

In this formulation, any gear can be selected as the standard.

A generalized linear model for estimating the parameters of Equation 5 for time-locations *i* = 1,2,..., *h* and gears *j* = 1,2,..., *k* is

$$y = \alpha + b_1X_1^{(b)} + \ldots + b_{h-1}X_{h-1}^{(b)} + g_1X_1^{(g)} + \ldots + g_{k-1}X_{k-1}^{(g)} + \varepsilon \quad (8)$$

where the parameters to be estimated are intercept α, time-location coefficients bi's, and gear coefficients gj's (Kutner et al., 2004; Fox, 2008). The independent X variables are discrete categorical or "dummy" variables, $X_i^{(b)}$ for time-locations and $X_i^{(g)}$ for gear types. Dummy variables are coded as for a standard two-way analysis of variance (ANOVA) model (cf., Kutner et al., 2004).

Bottomfish sampling data for research fishing and BotCam gears data contain a substantial proportion of zero observations resulting in highly skewed, non-normal distributions for CPUE. Observations were modeled following the 'delta' approach in which all observations follow a distribution with a discrete probability of obtaining a non-zero value, e.g., binomial, and in which positive value observations follow some continuous distribution, e.g., normal or gamma

(Pennington, 1983; Stefansson, 1996). Parameter estimation of Equation 8 was carried out in two separate stages. The first stage applied the model of Equation 8 to presence-absence data using logistic regression, and the second stage applied Equation 8 to non-zero CPUE observations using generalized linear regression. Substituting the model-predicted occurrence p from the logistic regression for CPUE in Equations 6 and 7 yields the fishing power for occurence, $\lambda(p)$. Likewise, substituting the model-predicted catch when present μ from the generalized linear regression for CPUE in Equations 6 and 7 yields the fishing power for catch when present, $\lambda(\mu)$. Multiplying the occurrence fishing power $\lambda(p)$ and the catch when present fishing power $\lambda(\mu)$ yields the overall fishing power $\lambda(CPUE)$. Separating the gear calibration components in this manner allows the flexibility to standardize bottomfish survey data for subsequent analyses using presence-absence observations, non-zero CPUE observations, or combined zero and non-zero CPUE observations.

Study Design

Data from missions SE1302 and SE1306 (Table 1, Fig. 3) were used for analysis of fishing power. Catch data for BotCam for this analysis were defined as the species-specific Max N values for a 15-minute sample. For these experiments, an individual targeted PSU was considered as a space block, with samples inside each PSU treated as replicates. PSUs which had consistently shown high biomass during Phase 1 missions were selected for intensive repeat sampling. This experimental design was chosen to maximize bottomfish encounter rates by each gear, generating paired samples necessary for developing gear-specific fishing power and calibration factors (Fig. 3). Each mission was designated as a time block. Space-time blocks that had at least one positive catch for each gear were included in the analysis for a given target species.

RESULTS

Phase 1: Sampling Methods Development

Standard Fishing Sample

The 'standard fishing sample' for the Research Fishing gear was refined over the course of Phase 1 sampling missions (Table 1). The general method was to fish within a target grid cell (500 × 500 m primary sample unit) for a specified amount of time. The fishing sample entails a series of ‘drifts’ within a target cell for a total fishing time of 30 minutes. For the initial experiment SE1102, 57.4% of the individual drifts stayed completely within the target cell without extending into adjacent cells. Based on this finding, the participating scientists and fishers collaborated on methods and navigational aids to improve the ability of fishing vessels to stay within the boundaries of a target cell during a fishing sample. For the next Research Fishing experiment, SE1208, 89.7% of the individual drifts remained fully within the target cell. Fishers and scientists also worked together between missions SE1102 and SE1208 to standardize the number of lines, the type and number of hooks per line, bait type per line, and the definition of 'active fishing time' for a 30-minute sample within a PSU.

BotCam Soak Time

In a companion study, Misa et al. (in review) found that the likelihood of recording species MaxN increased with longer bottom time. Species-specific MaxN values were recorded within 15 minutes after camera touchdown in 50% of deployments where a given bottomfish was present and within the first 30 minutes in 80% of deployments (Fig. 8).

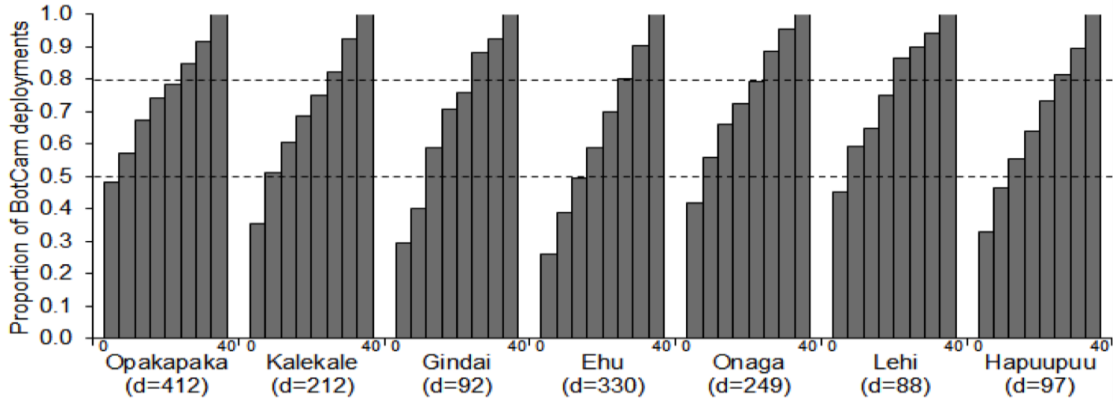

Figure 8.--Cumulative proportion of BotCam deployments where MaxN occurred as shown by 5-minute time bins from camera touchdown (minute 0) up to 40 minutes recorded from 1,504 BotCam deployments conducted during bottomfish surveys in the main Hawaiian Islands (figure from Misa et al [in review])). d = no. of BotCam deployments where a species was present.

For Phase 1 mission data, time-to-first sighting occurred within the first 15 minutes in about 75-85% of the samples where a given Deep-7 species was observed (Table 3, Fig. 9). The one exception was lehi, for which the time-to-first sighting was less than 15 minutes in 48 percent of the samples. The distribution of time-to-MaxN for a 45-minute period was shifted towards longer times compared to the time-to-first sighting (Fig 9).

Table 3.--Percentage of samples where time-to-first sighting occurred within the first 15 minutes. Sample size n is the number of BotCam samples in which a given species was observed. (table from Misa et al. [in review]).

Species	n	Time to First Sighting, % obs <15 min
Lehi	23	47.80%
Ehu	34	79.40%
Onaga	13	84.60%
Hapu'upu'u	6	83.30%
Opakapaka	68	76.50%
Kalekale	32	78.10%
Gindai	7	85.70%

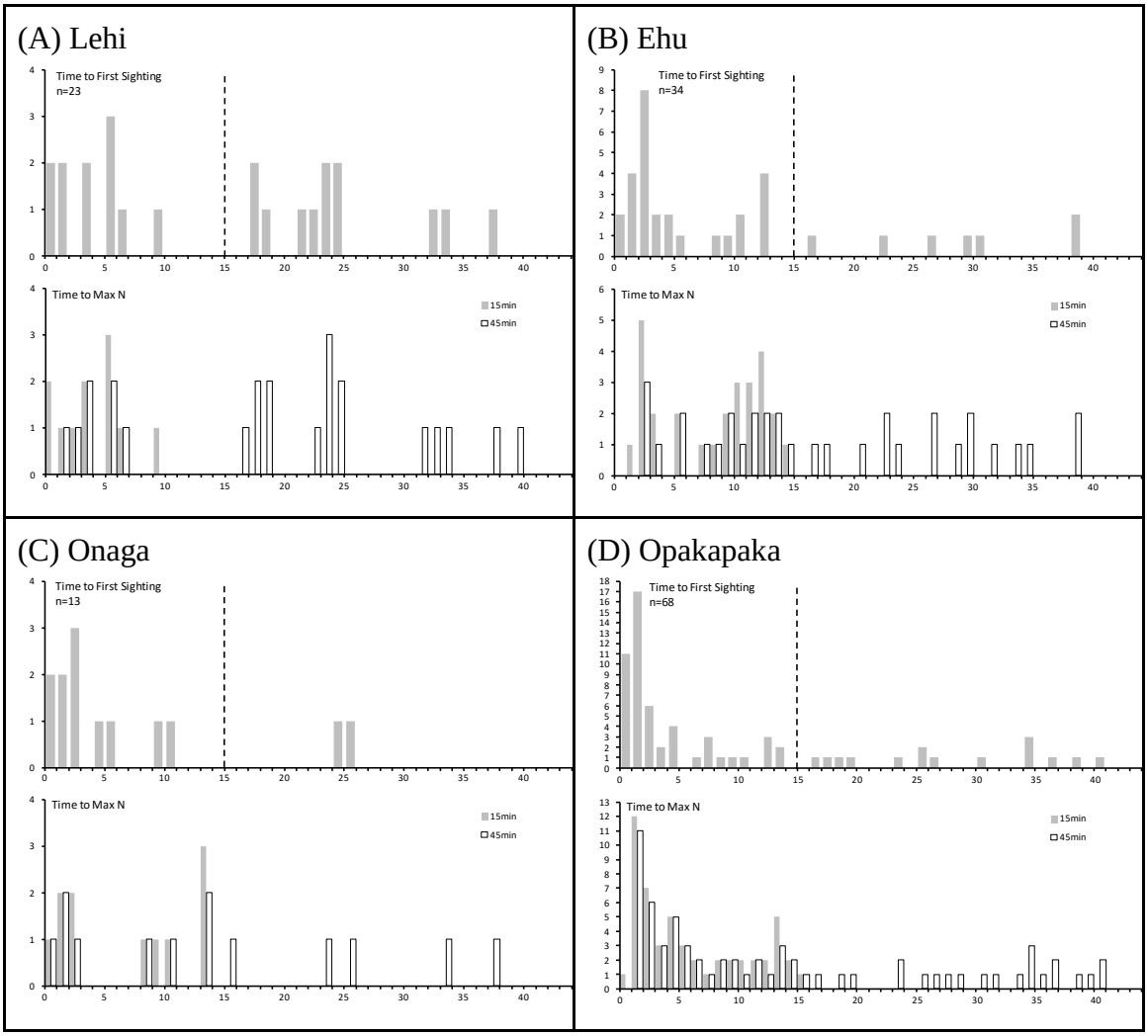

Figure 9.--Frequency distribution of time-to-first sighting (top panel) and time-to-maxN (bottom panel) for Deep-7 species: (A) Lehi, (B) Ehu, (C) Onaga, and (D) Opakapaka. Units for *x*-axis is minutes and for *y*-axis is number of samples.

Species and Length Composition

Data from experiments SE1102 and SE1208 (Table 1, Fig. 2) were used to analyze the species composition of fish captured/observed for research fishing and BotCam gears. Research fishing yielded 309 fish caught and BotCam yielded 1621 fish encounters (Table 4). The majority of individual fish captured/observed by the two gears were Deep-7 bottomfish species. About 84% of the fishes captured by the hook-line gear were either Deep-7 species or other species of bottomfish (snappers, groupers, jacks), suggesting that this gear is very targeted to Deep-7 species with a low bycatch of non-bottomfish species. Deep-7 and other bottomfish species accounted for about 73% of the fishes observed for the BotCam gear. The hook-line gear

captured a higher proportion of sharks compared to BotCam, and BotCam observed a wider range of the fish community compared to Research Fishing.

Table 4.--Species composition observed within research fishing catch and BotCam observational data. Both gears were highly selective for Deep-7 bottomfish, which made up 76% and 62% of the catch, respectively.

	Individual Fish Captured/Observed			
	Research Fishing		BotCam	
Species Group	Number	Percent	Number	Percent
Deep 7	236	76.4%	1001	61.8%
Other Bottomfish	22	7.1%	175	10.8%
Sharks	45	14.6%	11	0.7%
Other Fish	6	1.9%	434	26.8%
Total	309		1621	

Length data from Phase 1 experiments were compared for research fishing and BotCam. In general there was good correspondence in the length frequencies between the two gears for a given species, especially for cases with relatively high sample sizes (n > 20) for both gears (Fig. 10, Table 5). While differences in length-frequency distribution for kalekale and opakapaka were significant, owing to high sample sizes, the magnitude of these differences was minimal. BotCam did not commonly observe target species at sizes smaller than those captured by research fishing.

Table 5.--Size structure statistics for Deep-7 species by method. Minimum length, mean length, maximum length and SE for each species are reported in cm. Significant differences between methods (based on Kolmogorov–Smirnov tests) were found only for kalekale and opakapaka.

	Research Fishing					BotCam					KS Test	
Species	n	Min Length	Mean Length	Max Length	SE	n	Min Length	Mean Length	Max Length	SE	D	p
Ehu	139	18.50	38.67	60.00	0.78	45	22.40	38.75	60.00	1.38	0.12	0.75
Gindai	5	17.50	30.76	41.90	4.87	1	31.00	31.00	31.00	NA	0.60	0.93
Hapuupuu	2	70.00	74.00	78.00	4.00	5	62.60	74.42	98.60	6.40	0.60	0.57
Kalekale	175	18.50	36.25	43.00	0.33	125	21.30	32.15	50.40	0.55	0.43	**2.27E-12**
Lehi	2	65.00	74.50	84.00	9.50	39	32.20	70.79	89.90	2.25	0.35	0.98
Onaga	110	25.00	35.80	68.00	0.93	29	25.60	36.97	55.60	1.65	0.17	0.50
Opakapaka	169	26.00	39.97	75.00	0.94	191	26.20	44.19	69.90	0.89	0.23	**1.02E-04**

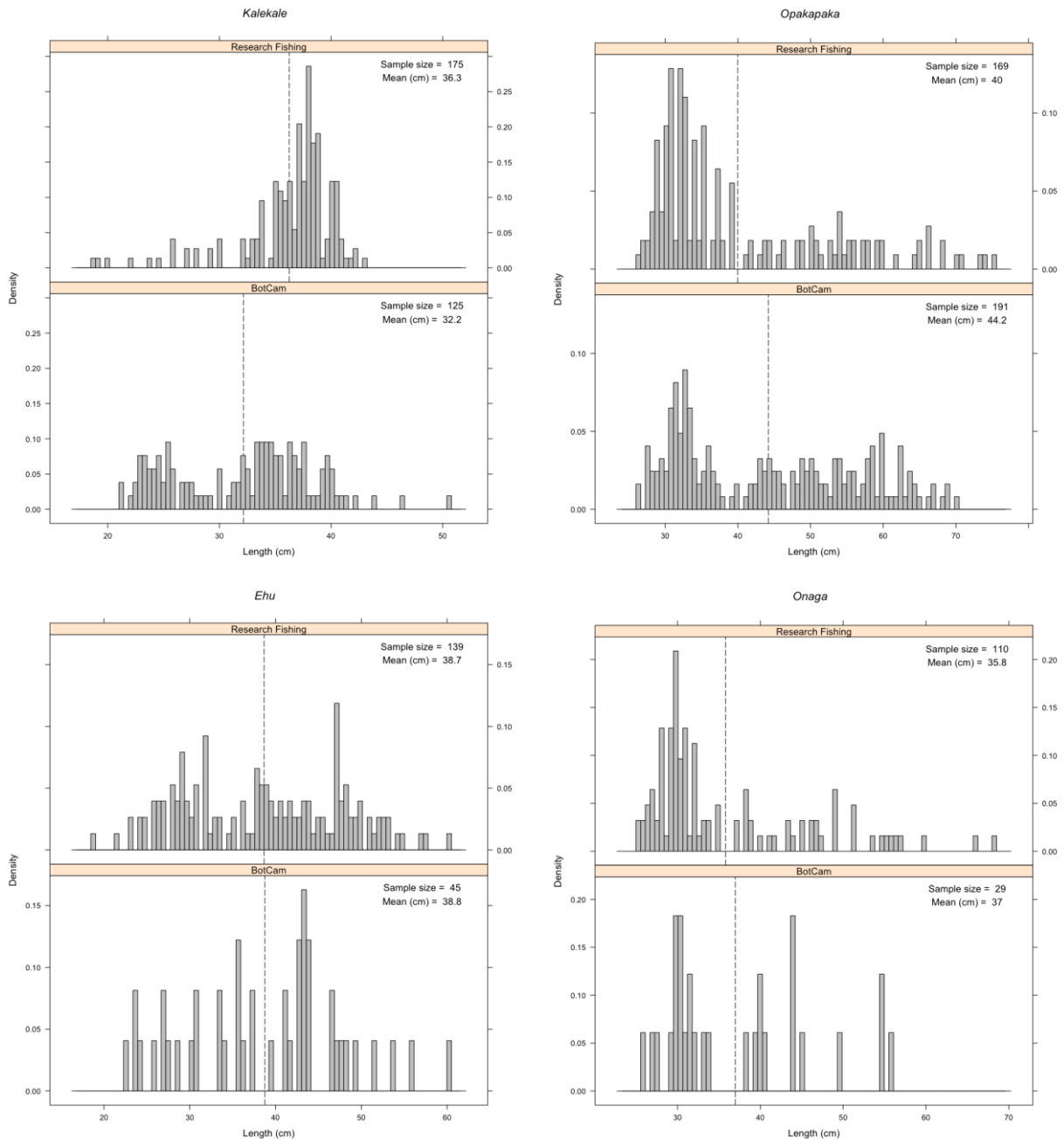

Figure 10.--Comparison of length frequencies derived from research fishing and BotCam for four of the Deep-7 species: Kalekale (Pristipomoides sieboldii), Opakapaka (Pristipomoides filamentosus), Ehu (Etelis carbunculus), and Onaga (Etelis coruscans). Sample size for Hapu'upu'u, Gindai, and Lehi was less than 10 individuals and insufficient for plotting. The vertical dotted line indicates the mean of the distribution.

Stratification Variables: Patterns by Habitat and Depth

Both habitat type and depth have been proposed as stratification variables for a full-scale fishery-independent survey of bottomfishes in the Hawaiian Archipelago. Data from experiments SE1102, SE1107, and SE1208, which had broad habitat and depth coverage, were used to evaluate habitat type and depth as potential stratification variables. Based on an initial analysis of depth and habitat type for bottomfish species, several arrangements of habitat type and depth were evaluated for stratification. Analysis of 3 habitat strata (hard-bottom-high slope, hard-bottom-low slope, soft-bottom) for 4 Deep-7 species are shown in Figure 11. In general, mean CPUE was higher for hard-bottom compared to soft-bottom habitats for all 4 species, and there were considerable differences in the variance (i.e., standard deviation) among habitat types. Depth was divided into two strata, 75–200 m and 200–300 m, for analysis. All 4 species exhibited strong depth preferences, with higher mean CPUE and variance for Opakapaka and Kalekale in depths less than 200 m and for Onaga and Ehu in depths greater than 200 m (Fig. 12). The 3 habitat strata and 2 depth strata were combined into 6 habitat-depth strata. The results of Fig. 13 show that this 6-strata scheme partitioned both the mean and variance of CPUE into different levels by combinations of habitat and depth for all 4 species; consequently, this combination stratification scheme appears to be more effective compared to stratifying by either

habitat type or depth alone. For BotCam, the same patterns of mean CPUE by depth and habitat were observed for 15-minute and 45-minute soak times for the 4 species.

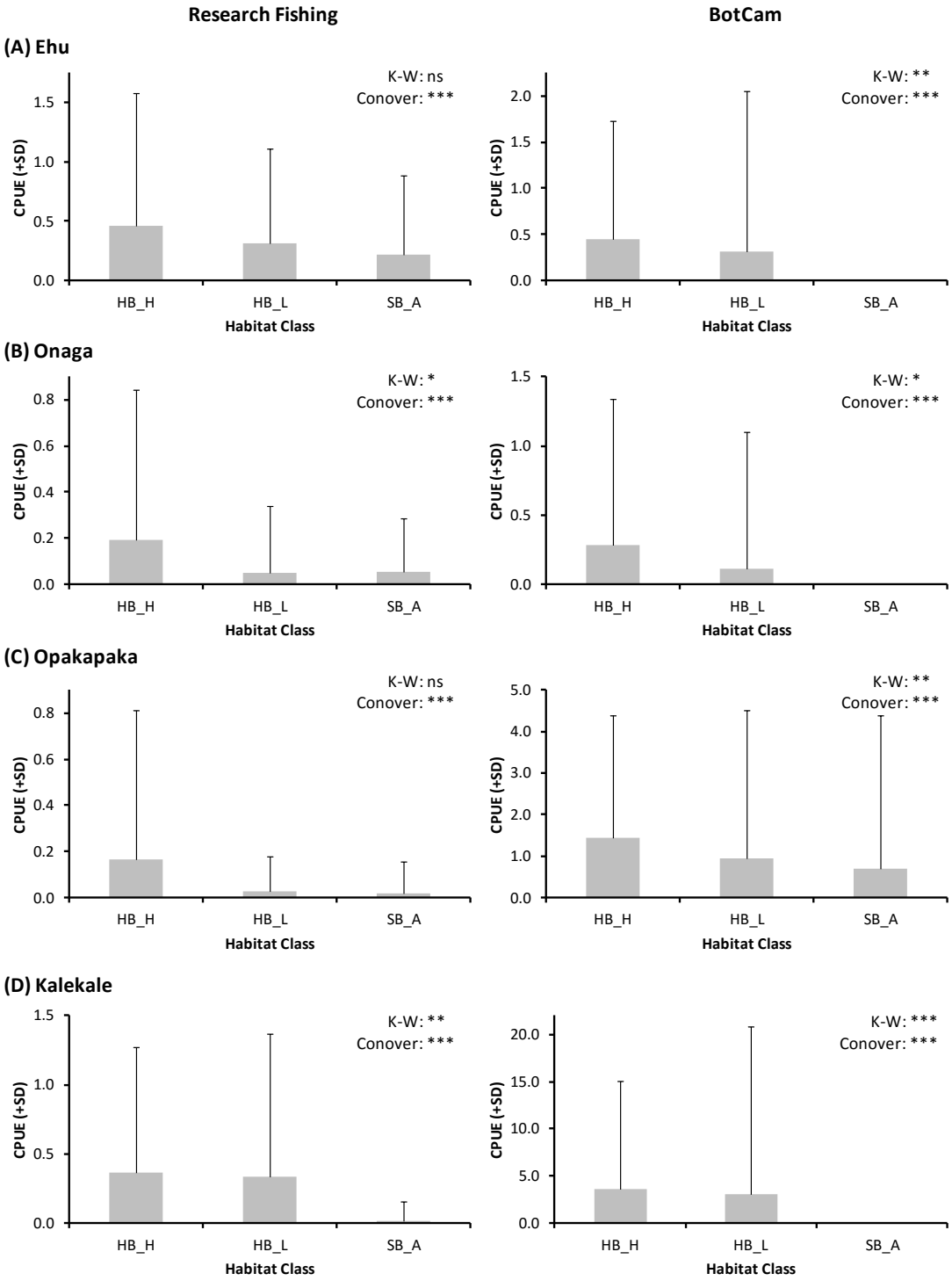

Figure 11.--Mean CPUE and associated standard deviation by habitat class for Research Fishing (left panels) and BotCam (right panels) gears for (A) Ehu, (B) Onaga, (C) Opakapaka, and (D) Kalekale. Non-parametric tests: Kruskal-Wallis (K-W) one-way ANOVA for differences in means; Conover one-way squared ranks test for differences in means and variances.

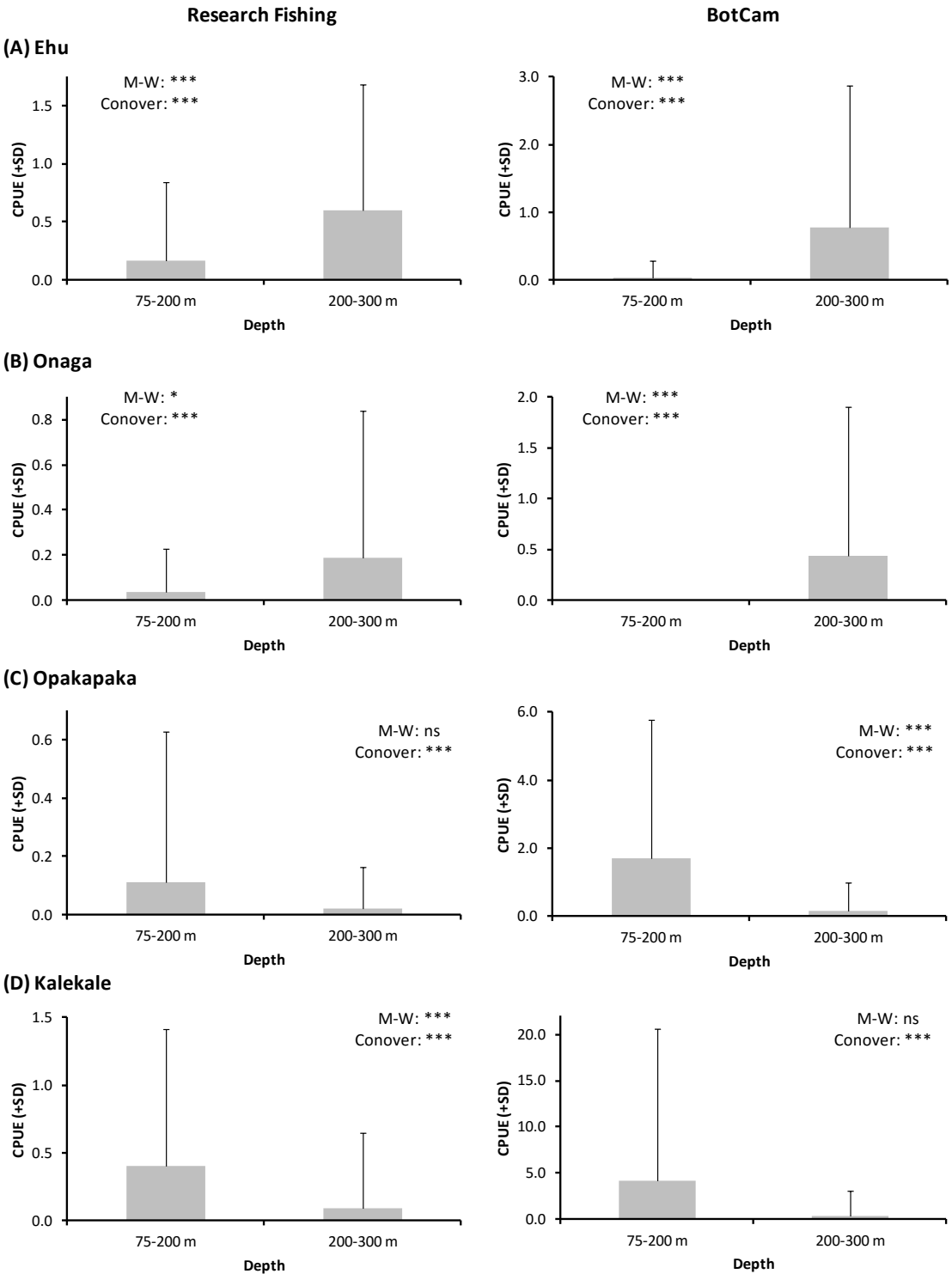

Figure 12.--Mean CPUE and associated standard deviation by depth range for Research Fishing (left panels) and BotCam (right panels) gears for (A) Ehu, (B) Onaga, (C) Opakapaka, and (D) Kalekale. M-W: non-parametric Mann-Whitney U-test for differences in means.

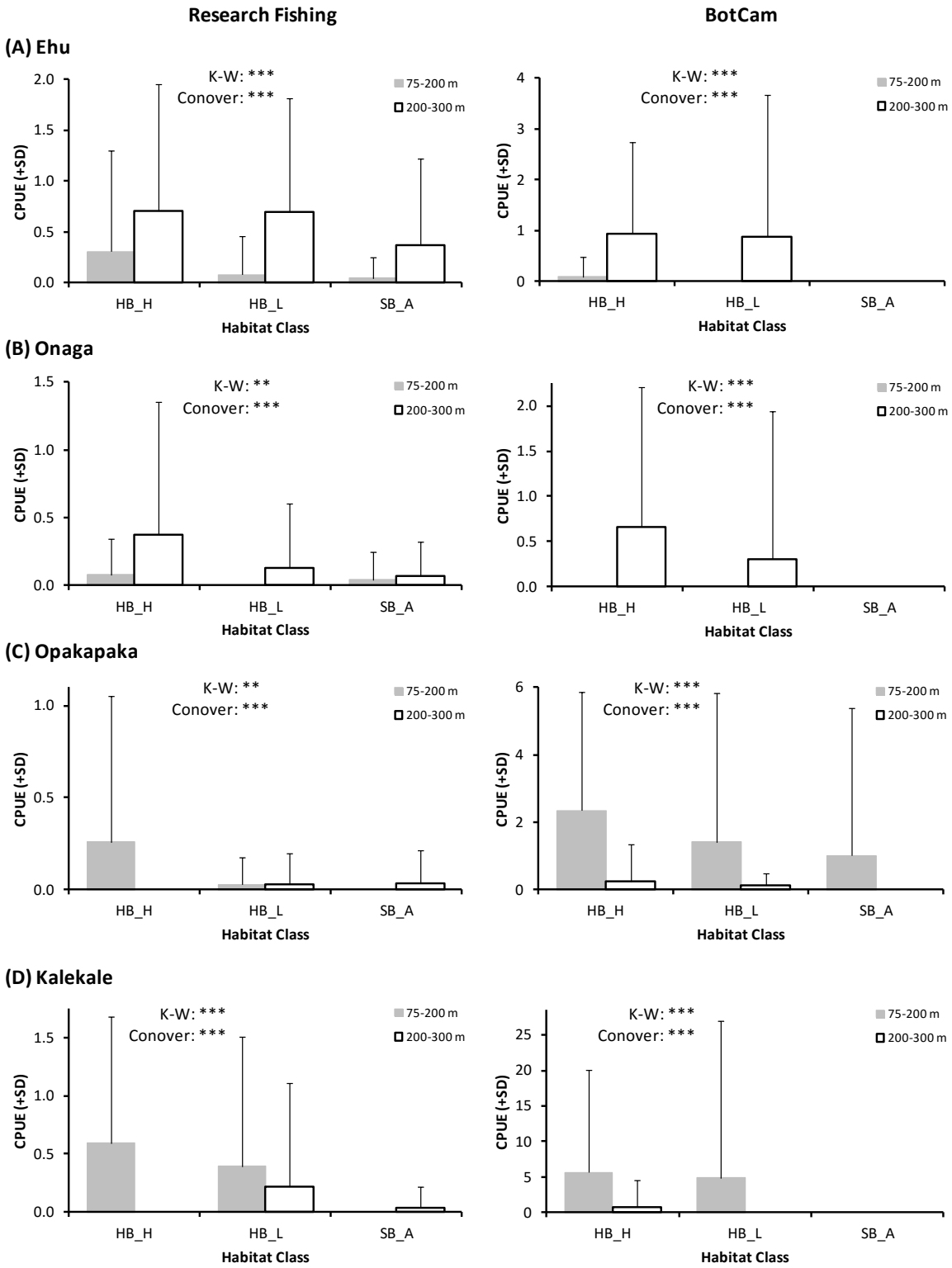

Figure 13.--Mean CPUE and associated standard deviation by habitat and depth for Research Fishing (left panels) and BotCam (right panels) gears for (A) Ehu, (B) Onaga, (C) Opakapaka, and (D) Kalekale.

Phase 2: Gear Calibration Experiments

Sufficient data for fishing power estimation was available for 4 Deep-7 species: ehu, opakapaka, onaga, and kalekale (Tables 6, 7, 8). Model-fitting diagnostics for the positive catch GLM suggested that error residuals were best modeled with either a gamma or normal probability density function for a given species (Table 6).

Table 6.--Number of space-time blocks and observations for the logistic and positive catch fishing power models for three species. Also shown are the selected response variable and error pdf for the positive catch GLM.

	Logistic GLM		Positive Catch GLM		Selected Positive Catch Model	
Species	Location-Time Blocks	n	Location-Time Blocks	n	Response Variable	Error pdf
Ehu	6	98	6	42	μ	gamma
Onaga	7	126	8	70	μ	gamma
Opakapaka	13	258	13	129	log(μ)	normal
Kalekale	14	238	14	93	log(μ)	normal

Table 7.--Sample sizes for the logistic (p) and positive catch (μ) GLM models by gear and species.

	Research Fishing		BotCam	
Species	n (p)	n (μ)	n (p)	n (μ)
Ehu	56	23	42	19
Onaga	70	40	56	30
Opakapaka	144	69	114	60
Kalekale	136	49	102	44

For the combined SE1302 and SE1306 experiments, mean occurrence was higher for research fishing for onaga, and higher for ehu, opakapaka, and kalekale for BotCam. Mean catch when present was higher for BotCam for all four species. Overall, the relative fishing power for CPUE was higher for BotCam compared to research fishing in all cases (Table 8).

Table 8.--Model-predicted mean occurrence (p), catch when present (μ), and CPUE by species and gear, and the associated fishing power for each metric. Note that research fishing was designated as the standard gear for this analysis.

		GLM Predicted Mean			Relative Fishing Power		
Species	Gear	p	μ	CPUE	λ(p)	λ(μ)	λ(CPUE)
Ehu	Research Fishing	0.376	1.957	0.735	1.000	1.000	1.000
	BotCam	0.438	2.722	1.191	1.164	1.391	1.620
Onaga	Research Fishing	0.569	2.634	1.500	1.000	1.000	1.000
	BotCam	0.513	7.406	3.800	0.901	2.811	2.533
Opakapaka	Research Fishing	0.452	1.774	0.801	1.000	1.000	1.000
	BotCam	0.534	4.340	2.316	1.181	2.447	2.890
Kalekale	Research Fishing	0.383	1.891	0.724	1.000	1.000	1.000
	BotCam	0.451	11.771	5.307	1.178	6.225	7.333

DISCUSSION

Efficacy of Research Fishing and Botcam Gears for Bottomfish Surveys

Commercial and recreational bottomfishing remain important components of the Hawaiian economy and culture. To enhance sustainability, the NOAA National Marine Fisheries Service, Pacific Islands Fisheries Science Center conducts an assessment of the Deep-7 stock every 3 years. To date, while assessments have taken into account short and long-term temporal effects (yearly and seasonal) as well as the effects of geography (HDAR reporting grid) and some differences among fishers when standardizing CPUE, these assessments have utilized only fishery-dependent data and have treated the Deep-7 species as a stock complex, rather than as individual species. Use of the types of advanced sampling technologies detailed in this study is aimed at improving species-specific, size-structured abundance estimates and, hence, the resulting assessments. Fishery-independent data can include data on portions of the stock before they recruit to the fishery, while the use of advanced technologies allows for increased precision and accuracy with respect to species-specific size-structured abundance. The inclusion of data from multiple gears helps to guard against bias associated with any particular gear.

Research Fishing

The hook and line methods employed by the Research Fishers most closely match the methods employed by the commercial and recreational fishery. Hence, data from research fishing is most directly comparable in kind to the catch data used in previous assessments. Cooperation with local fishers also helps to increase stakeholder buy-in while making use of local knowledge and skill. Research fishing operations can be conducted both day and night and hooks can be

positioned to catch fish throughout the water column. Research fishing also provides a high degree of accuracy and precision with respect to species identification and size. However, these advantages hinge on the expertise of the observer recording the information. In early iterations of this study, observers were inconsistent in their species naming and size measuring conventions, using local common names instead of scientific names and varying in their units of measure. There was also inconsistency in the way length measurements were taken, with some observers measuring total length while others measured fork length. Some used a measuring board while others used a flexible tape draped over the body of the fish. Such inconsistencies increased the variability in early research fishing data and necessitated many hours of data review, translation, and additional training. The variability between vessel captains and observers is one of the main challenges associated with data derived from research fishing. Differences in skill level, vessel type, and fishing style (e.g. drifting, power drifting, anchoring) can all lead to differences in CPUE and composition of the catch. Rigorous training resulted in improved data collection and recording procedures by the end of this study. Our results indicate that both bait types should be retained to comprise a standard fishing sample for surveys targeting the Deep-7 complex, but that catch should continue to be recorded separately for each bait type to allow continued refinement of the analysis of bait preference.

Less easily overcome, are challenges associated with gear saturation, behavior, and sampling logistics. In this study, each vessel fished a total of 2 lines with 4 hooks on each line. While differences between low and high densities of fish can easily be detected, once the gear becomes saturated (i.e., all the hooks have fish), it can be difficult or impossible to distinguish between high and very high densities. Similarly, research fishing is subject to false negatives. In several cases BotCam revealed fish in an area where target species were not biting and were thus not captured by fishing operations. This can be due to any number of factors including moon phase, time of day, water temperature, and type of bait being used, among many others. Properly quantifying false negatives remains a challenge for fishing operations. Research fishing operations are also typically fielded using small contract vessels (18–40 feet) that also take part in the fishery. This may be challenging to implement in an operational fishery-independent survey that covers the range of the stock as many of these vessels do not have the range to reach the outer boundaries of the stock. These less heavily fished areas have the potential to greatly influence an assessment. Research fishing is necessarily an extractive technology. While this is beneficial in ensuring correct species identification and size and allows for the collection of specimens for biosampling, it cannot be used in areas where extraction is prohibited (i.e., the State's bottomfish restricted fishing areas (BRFAs), MPAs, etc.) or if some future catch quota for a target or bycatch species is reached. Sampling within protected areas will continue to be important as, if they are effective (Sackett et al., 2014), they have the potential to influence the assessment.

BotCam

BotCam represents an effective, non-extractive means for collecting fishery-independent, species-specific, size-structured abundance estimates. Stationary stereo-video camera platforms, like the BotCam, have been used by researchers at the PIFSC and University of Hawaii—Manoa since 1995 (Ellis and DeMartini, 1995) and have been used to non-destructively sample bottomfish assemblages associated with the Hawaii BRFAs (Moore et al., 2013; Misa et al.,

2013; Sackett et al., 2014). Stereo-video camera systems provide a high degree of accuracy and precision with regard to species-specific, size-structured abundance estimates, can easily be deployed and recovered by a team of 2 to 4 minimally trained field staff, and provide standardized data collection regardless of the personnel deploying the system or location of deployment. Their small size and weight means that they can be deployed by hand off a variety of vessels, including cooperative research vessels.

Our results indicate that MaxN statistics from a 15-minute soak time likely characterize the abundance of Deep-7 species in the immediate vicinity of the BotCam gear, whereas the higher abundance metrics associated with a 45-minute soak time are likely due to the inclusion of fishes attracted from farther away. The 15-minute soak time likely samples Deep-7 fishes in a more restricted space compared to the 45-minute soak time, thus guarding against drawing fishes from adjacent PSUs and disparate habitat strata into the count. As MaxN was recorded within 15 minutes for 50% of deployments, time to first sighting occurred within the first 15 minutes for nearly 85% of deployments, and there was no significant difference in abundance metrics by habitat between the 2 soak times, we have adopted the 15-min soak time for BotCam, with the associated 37% reduction in cost per sample.

Species-specific length-frequency distributions were similar between BotCam and research fishing, suggesting that both gears were effectively sampling the same assemblages. BotCam units were easily deployed throughout the survey area and species were easily categorized and measured in the resulting video data. Interestingly, BotCam did not encounter the small, juvenile fishes that would typically be missed by hook-based fishing gears due to size-selectivity. As a video-based method not dependent on fish taking a hook, we expect false negative to be less of an issue for BotCam than for research fishing. Hence, the lack of small, juvenile fishes of Deep-7 species in the BotCam gear further suggests that this life stage does not reside in the same habitats and/or depths as the larger, adult life stages for these species (Moffitt and Parrish, 1996; Parrish et al., 1997). Misa et al., (2013) did observe small juveniles of opakapaka in hardbottom and softbottom low slope habitats but in shallower water than the adults (40–100 m). Juvenile onaga were only observed in the Pailolo channel despite sampling 6 sites throughout the main Hawaiian Islands. This could have important implications for stock assessment as the status of juvenile populations would not be captured in the survey design.

Unlike research fishing, the BotCam relies on ambient light and therefore, in the MHI, can only sample to a depth of 300 m during daylight hours. Essential Fish Habitat (EFH) for Deep-7 bottomfish extends to 400 m, rendering a significant portion of the habitat beyond the range of the BotCam. While the majority of non-commercial and likely the majority of commercial bottomfishing operations occur during the day, a significant portion of commercial fishing occurs at night, especially for opakapaka and onaga (Nichols and Nakagawa, pers. Comm.). These limitations should be considered as data from day-time, fishery-independent surveys are incorporated into stock assessment models. The use of imaging sonar, such as Didson™ or BlueView™, may enable enumeration and sizing of fish targets in zero-light. Species identification may prove more difficult, however, as the detailed morphology of the target is not visible in the EK60 images. BotCam is also typically deployed as a single unit at given height above the seafloor. While the field of view of the cameras is able to capture fish over a wide area, fishes existing at significantly shallower depths than that at which the BotCam is deployed,

will not be captured, resulting in false negatives. This limitation could be alleviated by deploying multiple BotCam units at varying depths along a single downline, or by using EK60 to target BotCam deployments to depths where bottomfish are apparent.

Stereo-video methods like BotCam commonly use the MaxN method for estimating abundance. While MaxN was developed as a conservative estimator to avoid double-counting individual fishes, estimated abundance can be biased upward or downward based on aspects of the assemblage (Schobernd et al., 2014). For species that form patchily distributed schools, MaxN may overestimate abundance as the density of a school seen in a single frame is applied to the overall sample. For species that do not school or exist at low densities, abundance may be underestimated. For example, multiple distinct individuals seen singly in different frames would be recorded as a single individual. The MaxN method also has the potential to bias size estimates. As size measurements are made at or near time of MaxN, mean size for the species may be downwardly biased as higher numbers of small individuals can fit within the finite field of view of the camera. For species where smaller size classes are more gregarious, size structure would, likewise be downwardly biased. This is a potential explanation for the single, large kalekale and opakapaka that were captured during research fishing operations, but which exceed the BotCam length-frequency distributions for those species.

The use of bait to attract target fishes to the field of view of the camera also has the potential to distort the sampling volume, with fishes being drawn from beyond the field of view of the camera. While less of an issue for estimates of relative abundance, uncertainty in the sampling volume presents a significant issue when attempting to generate estimates of absolute abundance. However, studies have found that variance of abundance estimates within habitats is reduced when bait is used compared to unbaited camera deployments (Harvey et al., 2007). The reduction in soak time from 45 to 15 minutes should significantly reduce bait-based bias, however, alternative sampling and video processing methods that could reduce this bias should continue to be investigated.

Data processing time remains an obstacle to the increased use of BotCam and other video-based methods. Translating the raw video footage into the species-specific size-structured abundance data required for use by stock assessors requires highly trained and skilled video analysts. The training period for a new analyst can easily take 6 months, and can vary among analysts, the number of species in question, and the complexity of the environment. Depending on the abundance and species diversity in a given sample, 15 minutes of stereo-video footage can take from 30 minutes to 12 hours to process, with an average processing time of 2.5 hours. In an operational context, stock assessment scientists would prefer to have numeric data within a few months of the end of a survey and it is unlikely that human analysis will be able to keep pace with data collection. Automated image analysis and video processing is an active area of research (Shortis et al., 2013) and NMFS has recently established a Strategic Initiative for Automated Image Analysis (NMFS, 2014). Development of automated methods for processing optical data streams are likely necessary before these data streams can regularly be used for routine assessments.

Research fishing and BotCam both produce relative metrics (CPUE and MaxN) of abundance. However, relative metrics are not typically used in stock assessment until a significant time

series has been developed. Before that time, such measures may have greater utility in the estimation of absolute abundance. This presents significant challenges, first of which is the issue of sample area, which can be affected by the duration of the survey, use of bait and by the behavioral interaction between the fish and the gear. Stereo-camera systems are typically deployed in a baited configuration. While bait is useful to attract the fish to the area immediately in front of the cameras, where they can be identified and measured, bait can also attract individuals from outside the immediate area, which is an issue for research fishing as well. The reduction in deployment time from 45 to 15 minutes should reduce this issue, but it is likely that the area of attraction still varies to some extent based on current speed, current direction, and benthic topography. While the identical bait mixture is used by both BotCam and research fishing, the use of bait may still produce varying individual and interacting behaviors among target species.

Catch Composition

Research fishing and BotCam were both selective for Deep-7 species with minimal bycatch, suggesting these gears are appropriate to include in an operational fishery-independent bottomfish survey. In general, there was good correspondence in species-specific length composition estimates between the 2 gears, especially for species with high sample sizes. The significant differences in length frequency distributions between the 2 gears for kalekale and opakapaka were likely due to the high samples sizes as the magnitude of the difference was minimal. Gindai and hapu'upu'u were rarely captured by either gear, suggesting that other methods will need to be devised to survey these species. While BotCam sample size for lehi was reasonable, few were captured by research fishing, suggesting that fishery-dependent methods may not be appropriate for sampling this species. BotCam did not record fish at sizes significantly smaller than those recorded by research fishing. A higher sensitivity of BotCam to smaller individuals was hypothesized due to hook-based size selectivity inherent to research fishing. The fact that smaller individuals were not observed in BotCam data suggest that juveniles may be utilizing different habitats or geographic regions than larger individuals, as other authors have reported (Moffitt and Parrish, 1996; Parrish et al., 1997). The apparent species-level differences in sensitivity of each gear type also suggest that surveying and assessing bottomfish as individual species may be more appropriate than treating bottomfish as a homogenous complex. Bottomfish catch in the MHI is dominated by opakapaka and onaga (Brodziak et al., 2014), and grouping the remaining species with these two likely does not accurately reflect their true abundance or how they respond to fishing pressure.

Fishing Power

The two-stage GLM approach enabled estimation of relative fishing power of research fishing and BotCam gears despite a high frequency of zero CPUE observations. The strategy of experiments SE1302 and SE1306, which entailed repeated intensive sampling by both gears in small space blocks (500-m grid cells) over a short time frame (10-12 days), yielded the most reliable data for estimating fishing power factors because time-space variation of sampling for bottomfish species was tightly controlled, thus enabling much clearer discrimination of differences in catchability between the 2 gears.

For the 4 species analyzed, model-predicted estimates of CPUE were higher compared to research fishing. This is likely due to the different 'catchability' or 'viewing' properties of the 2 gears. BotCam samples provide a localized estimate of the density of fish for target species, approaching the 'true' abundance within the viewing area of the camera. In contrast, research fishing only captures some fraction of the total fish available within the grid cell, those that will take the bait. Accordingly, the model-predicted estimates of CPUE were higher for the BotCam gear compared to research fishing.

Transition to Operations

The primary goal of this study is to evaluate and identify an effective and efficient suite of fishery-independent gears for sampling the main Hawaiian Islands Deep-7 bottomfish assemblage for use in an operational multi-gear, fishery-independent survey. The ultimate purpose is to improve the data products supporting stock assessments.

Refinements to Sampling Methods

Analysis of bait preference by species for Research Fishing was conducted utilizing fishing samples that deployed both bait types from experiments SE1208, SE1302, and SE1306. These samples were filtered to only include habitat-depth grid cells in which at least one Deep-7 species was either captured by Research Fishing or observed by BotCam. This ensured that the paired-bait samples occurred within Deep-7 habitats. Four Deep-7 species were analyzed, and the paired-bait samples were further filtered by species to exclude depths where a given species does not occur, i.e., deeper depths for Opakapaka and Kalekale and shallower depths for Onaga and Ehu. These filtering procedures had the effect of excluding fishing samples with zero or close to zero probability of occurrence from the analyses for the target species. A paired-sample t-test was used to analyze the difference in CPUE between bait types as the statistical observation, and evaluate whether this difference was significantly different from zero. A positive mean difference indicated preference for fish bait and a negative mean difference indicated preference for squid bait. The results are shown in Table 9. Mean CPUE was significantly higher for Onaga for fish bait and for Opakapaka for squid bait. Preference for either fish or squid bait was not observed for Ehu or Kalekale. These findings suggest that both squid and fish bait should be retained in operational research fishing surveys.

Table 9.--Analysis of bait preference for four Deep-7 species. Sample size n is the number of paired fish-squid fishing samples used in the analysis.

		CPUE, Fish Bait		CPUE, Squid Bait		Paired Sample t-test CPUE Difference, Fish - Squid		
Species	n	Mean	SE	Mean	SE	Mean	SE	Sig.
Ehu	116	0.3793	0.0710	0.2931	0.0505	0.0862	0.0677	ns
Onaga	106	0.6415	0.1170	0.4245	0.0975	0.2170	0.0967	p<0.05
Opakapaka	198	0.3384	0.0604	0.4899	0.0764	-0.1515	0.0589	p<0.05
Kalekale	240	0.3750	0.0666	0.3917	0.0659	-0.0167	0.0426	ns

For BotCam, the change from a 45-minute to 15-minute soak time may have resulted in an

effective sample area that was smaller than the PSU; thus, more than one camera deployment may be required to adequately characterize each 500 × 500 m cell. This issue was investigated using data from SE1302. In this experiment, a small set of PSUs of the most favorable habitat type for Deep-7 species, HB_H, was sampled repeatedly by both fishing and BotCam gears. These data were analyzed with respect to a two-stage survey design (Cochran, 1977; Smith et al., 2011). Each BotCam drop within a given PSU was considered a second-stage unit (SSU). The optimum number of SSUs to sample within a given PSU, m*, was estimated from

$$m^* = \frac{\sqrt{s_2^2}}{s_u} \tag{9}$$

where s_u is the sample standard deviation,

$$s_u = \sqrt{s_1^2 - \frac{s_2^2}{M}} \tag{10}$$

and s^2_1 is the sample variance among PSUs, s^2_2 is the sample variance among SSUs, and M is the total number of SSUs in a given PSU. For this analysis, there were n = 14 PSUs sampled with a total of nm = 218 drops for an average m of about 15 to 16 SSUs per PSU. Since the area of an SSU is unknown, a set of plausible SSU cell sizes was evaluated ranging from 50 × 50 m to 150×150 m. Estimates of m* for 5 Deep-7 species were mostly around m* = 3 SSUs per PSU for each species (Table 10). The target m was rounded to the next highest integer (Cochran, 1977). Results suggest that there is some heterogeneity of variance of CPUE among BotCam drops within a PSU, and that conducting 3 drops per PSU would be optimal for controlling this variance.

Table 10.--Analysis of m*, the optimum number of BotCam drops per 500 × 500 m grid cell, for five Deep-7 species. Standard deviation of CPUE was estimated from eq. (2); M is the total possible SSUs within a PSU (500-m grid cell).

Species	SSU Cell Size	M	Mean CPUE	SD CPUE	m*	Target m
Lehi	150 x 150 m	11.1	0.641	0.590	3.7	4
	100 x 100 m	25.0	0.641	0.768	2.9	3
	75 x 75 m	44.4	0.641	0.821	2.7	3
	50 x 50 m	100.0	0.641	0.857	2.6	3
Ehu	150 x 150 m	11.1	0.215	0.402	2.8	3
	100 x 100 m	25.0	0.215	0.475	2.4	3
	75 x 75 m	44.4	0.215	0.498	2.3	3
	50 x 50 m	100.0	0.215	0.513	2.2	3
Onaga	150 x 150 m	11.1	0.431	0.793	3.1	3
	100 x 100 m	25.0	0.431	0.968	2.6	3
	75 x 75 m	44.4	0.431	1.022	2.4	3
	50 x 50 m	100.0	0.431	1.059	2.3	3
Opakapaka	150 x 150 m	11.1	1.021	0.988	3.3	4
	100 x 100 m	25.0	1.021	1.225	2.6	3
	75 x 75 m	44.4	1.021	1.297	2.5	3
	50 x 50 m	100.0	1.021	1.347	2.4	3
Kalekale	150 x 150 m	11.1	1.365	1.124	5.7	6
	100 x 100 m	25.0	1.365	1.830	3.5	4
	75 x 75 m	44.4	1.365	2.019	3.2	4
	50 x 50 m	100.0	1.365	2.145	3.0	3

Gear Development

Both research fishing and BotCam are able to provide usably accurate and precise species-specific size-structured abundance data in a reasonable period of time. Both gears have relatively low equipment costs and can be deployed by small field teams using small to medium-sized cooperative research vessels. Based on the evaluation thus far, these gears appear adequate for operational use in an assessment survey.

While AUVs and EK60 show promise, significant challenges remain with their operational use for Hawaii bottomfish surveys. The SeaBED AUV can provide important information across habitat gradients or focused on particular areas of interest, however, high equipment costs, large field team requirements and low sample numbers, make it difficult to deploy as a survey tool across the operational survey domain. With technological advancement, cost reductions, and the ability to operate multiple AUVs simultaneously and independently from large research vessels, their applicability to operational surveys will likely increase.

Resources should also be devoted to the development of robust methods for accurate and precise analysis of stereo-video data, whether from stationary or mobile camera systems. For stationary camera systems, the MaxN method is well supported in the literature ((Ellis and DeMartini, 1995; Priede et al., 1996; Willis et al., 2000; Cappo et al., 2003; Gledhill et al., 2005; Merritt et al., 2011; Misa et al., 2013)). However, recent papers by (Schobernd et al., 2014) suggest that alternative methods may better reflect the assemblage. Additional research should be devoted to development of robust methods to estimate size-structured abundance from stereo-video data. Finally, timely analysis of stereo-video data from an operational survey could quickly exceed the capabilities of human analysts. Automated tools to extract estimates of species-specific, size-structured abundance from stereo-video data are sorely needed.

EK60 has the unique ability to identify targets simultaneously throughout the water column during both day and night operations. However, the inability to distinguish among Deep-7 species and between bottomfish and non-bottomfish severely hampers the utility of these data. Additional research and development should be devoted to parsing EK60 data into accurate and robust species-level estimates of abundance and biomass. Further validation of EK60 data through simultaneous EK60 and optical data collection will improve our ability for species- or taxa-specific estimates of size-structured abundance. Development of broadband acoustic methods could also provide significant improvements. Until such time as EK60 data can be attributed to species or taxonomic group, they will be of limited utility. Currently at PIFSC, the EK60 system is operated from the NOAA Ship *Oscar Elton Sette*. Availability of this high-cost asset is increasingly limited. Further, this single asset cannot be simultaneously deployed in each survey zone. Portable EK60 systems exist and, if they can be operated from cooperative research or small contract research vessels, would be of greater utility. As with stereo-video data, significant resources will need to be devoted to analysis of the large volume of data from an operational survey.

Survey Domain and Sample Size Projections for the Main Hawaiian Islands

The Hawaii Department of Aquatic Resources (HDAR) divides the waters of the MHI into 82 nearshore and coastal commercial bottomfish reporting grids (Fig. 14). Bottomfish EFH (100–400-m depth range) within these reporting grids encompasses the logical range for the stock and therefore the spatial domain for an operational fishery-independent survey (Fig. 14). This area comprises 31,083 PSUs that, where habitat maps exist, can be stratified by both depth and substrate composition. Our results suggest that an effective scheme for depth stratification/blocking would be to divide depth into 2 intervals, the first interval < 200 m and the second > 200 m, resulting in the stratification given in Table 11.

Figure 14.--The main Hawaiian Islands sampling domain. An operational fishery-independent survey would cover the Hawaii Department of Aquatic Resources (HDAR) commercial fishery reporting grids and would be constrained to the 100–400-m depth range utilized by Deep-7 bottomfish species. The area (red color) is gridded at 500-m resolution and, where possible, stratified by depth, substrate composition, and slope. To facilitate sampling logistics, the area is divided into 4 zones. Each survey gear would be simultaneously allocated to PSUs within each zone, utilizing cooperative research vessels. It is estimated that sampling could be accomplished using 4 vessels in each zone.

Table 11.--Number of MHI primary sampling units (PSU) by survey zone, depth, and habitat strata.

Habitat	Depth	Zone									
		ALL		1		2		3		4	
		n	%	n	%	n	%	n	%	n	%
All	All	31083		2558		3615		17343		7567	
Hardbottom, High Slope	75-200 m	1281	4%	-	-	1	0%	1280	7%	-	-
	200-400 m	1127	4%	-	-	4	0%	1123	6%	-	-
Hardbottom, Low Slope	75-200 m	3455	11%	-	-	17	0%	3438	20%	-	-
	200-400 m	3389	11%	-	-	4	0%	3385	20%	-	-
Softbottom, Any Slope	75-200 m	2190	7%	-	-	4	0%	2186	13%	-	-
	200-400 m	2369	8%	-	-	-	-	2369	14%	-	-
Unclassified	75-200 m	9295	30%	1455	57%	1630	45%	3217	19%	2993	40%
	200-400 m	7977	26%	1103	43%	1955	54%	345	2%	4574	60%

The 2011 stock assessment of the main Hawaiian Islands Deep-7 bottomfish complex (Brodziak et al., 2011) highlights 22 of these reporting areas as having an estimated average relative abundance higher than that of the Penguin Bank reference area (area 331) (Fig. 15). These areas span the MHI with the exception of the islands of Oahu and Kauai. To efficiently survey the stock across its range, we propose dividing the area into four zones (Niihau-Kauai, Oahu, Molokai-Lanai-Maui-Kahoolawe, and Big Island) (Fig. 16) and to stratify the area by depth, substrate composition, and slope, as outlined above.

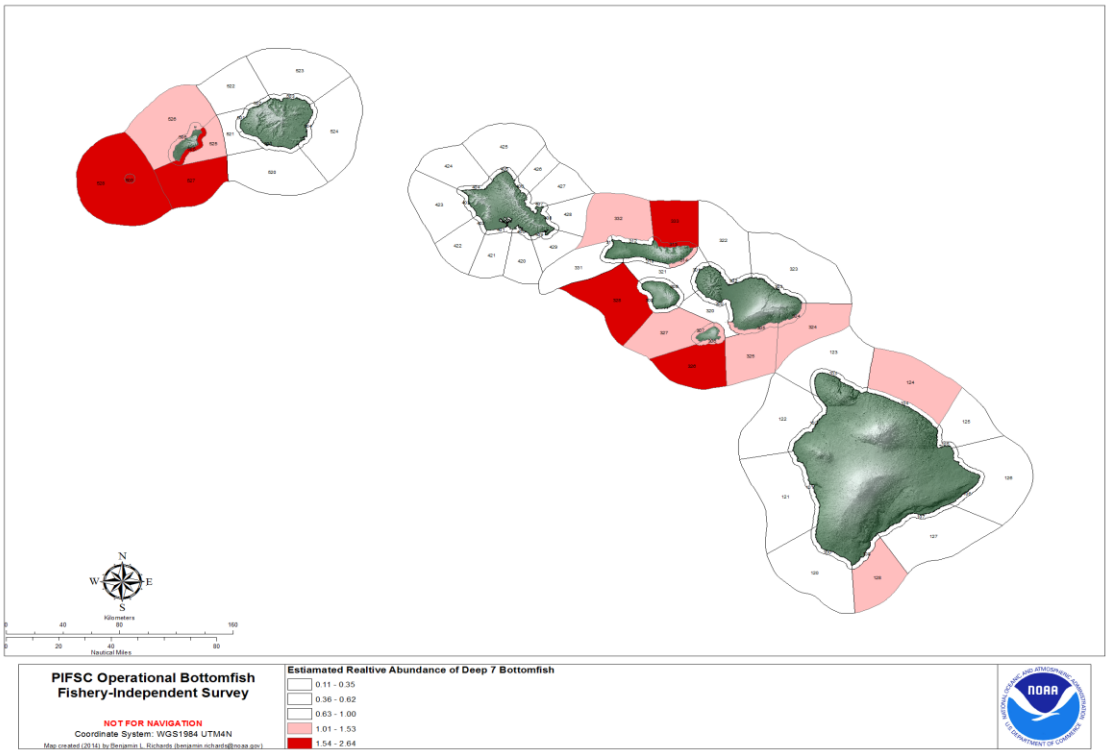

Figure 15.--A map of the 82 nearshore and coastal HDAR commercial bottomfish reporting areas highlighting (red) the 22 areas where the 2011 stock assessment of the main Hawaiian Islands Deep-7 bottomfish complex estimates an average relative abundance higher than that of the Penguin Bank reference area (area 331). Areas of highest estimated average relative abundance are situated around the islands of Niihau and Kaula Rock as well as in the Maui Nui region.

The first section of this report is based on surveys conducted in Zone 3, which comprises the center of the MHI commercial bottomfish fishery and where comprehensive high-resolution bathymetric and substrate composition maps are available. Before a stratified-random sampling design for the full MHI can be completed, comprehensive habitat maps with standard classifications and data ranges must be developed. While bathymetric and therefore slope data exist for most areas, useful substrate composition data do not (Fig. 16). These data have been collected for much of zones 1, 2, and 4, but have been collected using a wide variety of sensors and using a variety of scale ranges, such that similar numeric values from disparate areas do not signify similar levels of substrate composition (Chris Kelley, pers. comm.). The lack of a usable synthesis product across all zones is a major impediment to the development of a properly stratified operational fishery-independent survey for MHI bottomfish.

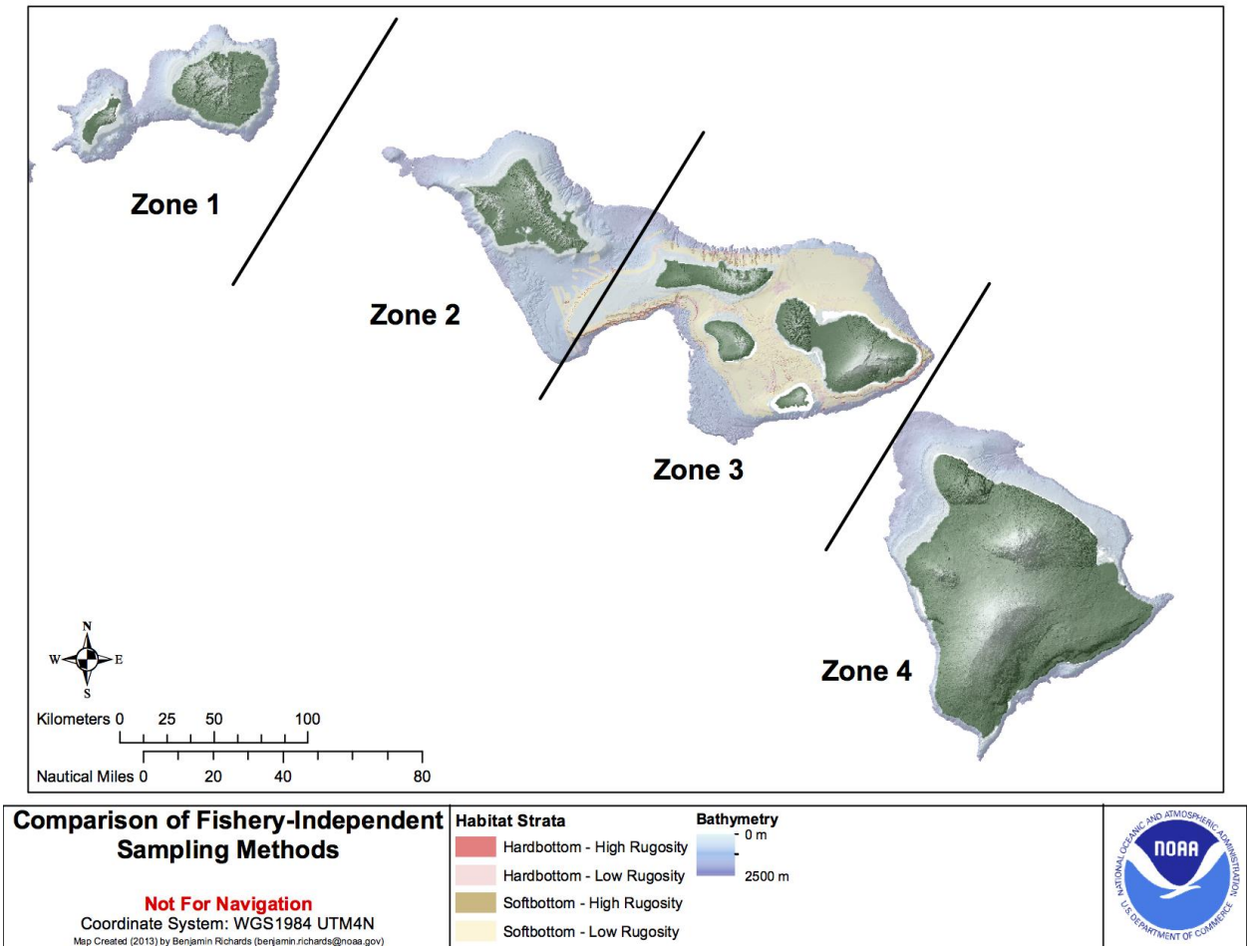

Figure 16.--A map of the 4 proposed research zones for an operational multi-gear fishery-independent survey of Deep-7 Bottomfish in the main Hawaiian Islands. Bathymetric GIS layers (blue gradient) exist for the full sampling domain. Substrate composition (red, pink, tan, and yellow in the above map) is currently available only for zone 3. Incorporation of existing substrate composition information into an expanded synthesis layer that covers the full sampling domain is necessary for a properly stratified experimental design for a domain-wide operational survey.

Cooperative research or contract vessels are the most efficient means for deploying research fishing and BotCam operations. Data for ehu, which prefers fish bait and deeper water (> 200 m), and opakapaka, which prefers squid bait and shallower water < 200 m) were used to generate power curves to determine initial sampling effort for an operational survey. The required sample size n*, i.e., number of primary sample units, to achieve a specified variance of CPUE in a future survey, was estimated by

$$n^* = \frac{\left(\sum_h w_h s_h\right)^2}{V + \frac{1}{N}\sum_h w_h s_h^2} \tag{11}$$

where w_h is the stratum weighting factor, i.e., the proportion of total sample units N in stratum h, s_h is the stratum sample standard deviation, and V is the desired variance of CPUE. The desired variance was estimated using a target CV for mean CPUE for the stratified domain (Ault et al., 1999). Values of w_h were determined from the GIS sampling grid for the main Hawaiian Islands, and estimates of s_h were obtained from research studies conducted in the Maui Nui region. The projected number of PSUs necessary to obtain a 15% CV of mean CPUE was 245 for ehu and 504 for opakapaka (Fig. 17) . The trio of research fishing vessels used in field operations to-date typically sample 18 PSUs per day. BotCam has typically completed 6 PSUs per day (3 replicates in each PSU). The combined total of around 24 PSUs per day, suggests that a 285 target PSUs would require approximately 10 days of sampling, 504 PSUs would require 21 days. Taking into account the greater spacing of PSUs in an MHI operational survey and the associated increased in transit time between sites, we suggest the use of 4 or more cooperative research vessels and a sampling window of 21 days.

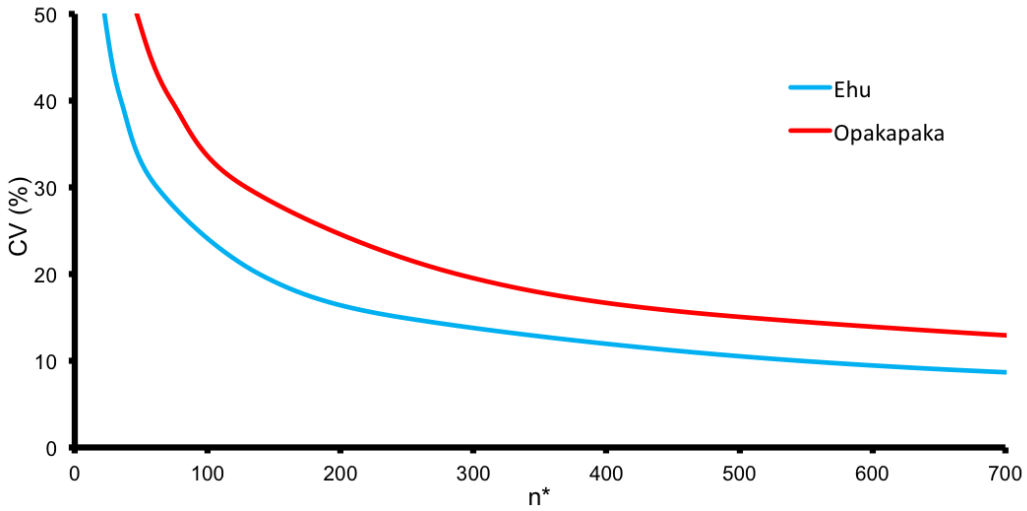

Figure 17.--Sampling power curve for ehu and opakapaka based on strata-specific variance estimates from the Maui Nui region and extrapolation of Maui Nui habitat relative abundance to other MHI zones. Approximately 245 and 504 samples are required to achieve 15% CV for ehu and opakapaka, respectively.

These initial recommendations are based on extrapolations of habitat-class prevalence from the Maui Nui area species-specific variance structure within each habitat class observed in Maui Nui to the rest of the MHI. To make the estimates more robust, synthesized substrate composition maps must be produced for the entire survey domain and samples must be collected in each of the strata within zones 1, 2, and 4, to ensure that variance estimates within strata are consistent across the MHI or, if not, that appropriate zone-and-strata-specific variance estimates can be used to guide sampling. The multibeam backscatter data needed to construct a synthesized substrate composition map for the MHI have already been collected and the resources necessary to create the synthesis product are available (Chris Kelley, pers. comm.). At this point, all that is required is funding to convert the existing data products to a range scale common across the MHI. This work could be completed in approximately 3 months.

Mission SE1402 conducted a pilot survey for full MHI-wide sampling. Gears were allocated in a stratified-random design to PSUs across the full Maui-Nui study area (Table 1, Fig. 4) to allow for the development of initial overall abundance indicators based on strata-specific estimates.

Relative Costs of BotCam and Research Fishing Gears

We compared costs to field each survey gear based on a cost per sample calculation. Cost per sample was defined as the total funding allocation required to mobilize, field, and demobilize the gear as well as costs to annotate or transcribe the data to the point where it was ready for analysis, divided by the number of samples that were collected during a standard 10-day field mission. This includes all equipment, vessel and personnel costs. For BotCam, we calculated cost per sample based on the number of deployments that could be conducted using both 45 and 15-min soak times. Relative costs of BotCam soak-time options were analyzed by comparing the number of samples per day that had been collected using a 45-min soak time during survey missions SE1102, SE1107, and SE1208 to the number of samples collected per day using a 15-min soak time during missions SE1302, SE1306 and SE1402. In our evaluation we also included the cost in human hours to process the video data from 45-min vs. 15-min deployments (calculate MaxN and measure individuals).

Based on in-the-field trials, reducing soak time for BotCam from 45 minutes to 15 minutes resulted in a 47% increase in the number of deployments that could be accomplished each day and a 37% reduction in cost per sample. Cost per sample from a 15-min BotCam soak time was 46% higher compared to that from 30-min research fishing surveys.

Seasonality

Little is known regarding the spawning behavior and meso-scale movement patterns of bottomfish in the main Hawaiian Islands (Western Pacific Regional Fishery Management Council, 2012). Several studies, mainly from the 1980s, have investigated life history and spawning seasonality of deepslope bottomfish species in Hawaii (Table 12). Many of the Deep-7 species exhibit similar life history traits (Andrews et al., 2014). For the majority of species, spawning appears to occur in the summer, with the exception of hapu'upu'u, which appears to spawn in the early spring (Andrews et al., 2014). While Andrews et al. cite a Western Pacific Regional Fishery Management Council report (2012) and state that opakapaka appear to have a

slightly longer (10-month) spawning period compared with the 6-month period common to onaga and hapu'upu'u, others believe these spawning periods to be overstated (DeMartini, 2014, pers. comm.). Uchimaya and Tagami (1984) provide a detailed discussion of bottomfish spawning in the Northwestern Hawaiian Islands. Spawning season was determined by the seasonal distribution of mean gonadal somatic indices (GSI). Using this method, these authors determined spawning seasons for opakapaka peaked in August with ripe ovaries collected from June through December. Onaga spawning peaked in August and September. Ehu spawned from May through October, with a peak from July to September. Kalekale peaked in August and September, with ripe ovaries collected from June through September. Gindai with ripe ovaries were collected only in August. Hapu'upu'u were anomalous, with individuals with ripe ovaries being collected in January and February. Everson (1989) also used GSI to determine that female onaga began maturing in June but that fully ripe ovaries were not found until July, with a spawning peak in October. GSI values dropped sharply in November and the incidence of completely or partially spawned individuals increased abruptly.

Unfortunately, literature on seasonal movement patterns appears sparse, with the majority of movement studies focusing on movement with respect to marine protected areas or between islands. Weng (2013) used acoustic telemetry to track the movement of opakapaka, onaga, and ehu on the eastern side of Ni'ihau and documented occasional movement of individuals across the boundaries of bottomfish restricted fishing areas. Importantly, movements beyond the limits of the detection network could not be recorded, so it is not known how far individuals may have ranged outside the small study area. Preliminary tag-recapture results from Okomoto (1993) indicate limited movement of opakapaka, primarily within 3 miles of the release site. Two conventional tagging studies described by Weng (2013) and O'Malley (2015), which suffer from limited recapture rates, show that the majority of medium size individuals were recovered near the tagging locations, with some inter-island movement. Opakapaka, in particular, did not exhibit regular large-scale horizontal movement, with only two fish recaptured more than 30 km from location of release (O'Malley, 2015). Overall, of the 81 opakapaka that were recaptured, the majority (53%) moved less than 1 km, 33% moved 1-5 km, 5% moved 5-10 km, 4% moved 10-20 km, and 6% moved > 20 km. A single opakapaka traveled from Penguin Bank off Molokai to Makapu'u Ledge, Oahu. However, the results of these studies should be taken with caution due to the paucity and limited size range of recaptures. Due to paucity of recaptures, analyses of movement seasonality could not be completed.

Haight et al. (1993) discuss one anecdotal observation of opakapaka spawning behavior in the Northwestern Hawaiian Islands in mid-April: "A commercial fisherman using a chromoscope depth sounder observed an opakapaka aggregation at about 150 m become very dense during the mid-morning hours. Catch rates decreased at this time, and egg masses were observed adhering to the fishing gear. By mid-afternoon the fish school became less compacted and catch rates increased. Opakapaka caught during this time were in spawning condition, some fe-males released eggs and males released milt. Free-floating eggs were noted covering a large surface area around the vessel."

Table 12.--Spawning months for Hawaii Deep-7 Bottomfish species.[1]

	January	February	March	April	May	June	July	August	September	October	November	December
Opakapaka				x[7]		x[2,3,4]	x[2,3,4]	**X**[1,2,3,4]	x[3,4]	x[3,4]	x[3,4]	x[3,4]
Onaga							x[6]	x[4,6]	x[4,6]	**X**[6]		
Ehu					x[4]	x[4]	**X**[4]	**X**[4]	**X**[4]	x[4]		
Kalekale						x[4]	x[4,5]	**X**[4,5]	**X**[4,5]			
Gindai								x[4]				
Hapu'upu'u	x[4]		x[4,8]	**X**[8]	x[8]	x[8]						

[1]Kikkawa 1980, [2]Ralston 1981, [3]Kikkawa 1984, [4]Uchimaya and Tagami 1984, [5]Everson 1984, [6]Everson et al. 1989, [7]Haight et al. 1993, [8]DeMartini et al. in press.

The peak of the spawning season for the majority of the Deep-7 species appears to occur in August and September, with few exhibiting any spawning behavior from January through March. In order to provide a representative estimate of the spatio-temporal distribution of the stock, including spawning, recruitment and migration, operational survey efforts should be timed to avoid periods when individuals are in transition, e.g. moving to or from spawning areas. Biannual surveys, which may be more practicable, but which may miss some of the more detailed seasonality in the stock, should therefore be conducted in the January–March period to capture the non-spawning period and again in August or September to capture the spawning period. The limited information currently available suggests that Deep-7 bottomfish do not exhibit regular large-scale horizontal movement patterns and there is little, if any, information available on whether seasonal and/or spawning-related movements occur. In the absence of compelling information, specific timing of a fishery-independent survey may not be able to consider biological movement patterns. If, however, the anecdotal report in Haigh et al. (1993), that species aggregate to spawn and that catch rate briefly decrease during actual spawning events, is correct and common, timing of survey effort could be important. Abundance estimates would be inflated by a high number of aggregations in the survey effort and conversely deflated by low numbers. Abundance estimates from fishing surveys would be deflated if catch rates decrease during spawning. More research on spawning seasonality, movement, and behavior is needed to provide better clarity in these areas, however, it may be advisable to avoid the August peak spawning period.

Data for Stock Assessment

The proposed multi-gear fishery-independent survey will provide essential information for the assessment of insular fishery resources in the main Hawaiian Islands, especially the Deep-7 bottomfish complex. There are 3 primary types of information that will be collected. First, the survey will provide information on the life history parameters of bottomfishes and other fishery resources through the direct collection of samples from the research fishing. Fish will be sampled for length, weight, age, maturity stage, and fecundity using a probability-based sampling scheme to characterize the life history parameters of botttomfishes. This information will be analyzed by the PIFSC as well as collaborating universities. These analyses will provide a reliable time series of information on bottomfish which will be fill a severe data gap in life history parameters that has been noted as an impediment to conducting structured stock assessments in the region (PIFSC, 2014) and measuring the potential productivity of fishery resources.

[1] **BOLD CAPS** denotes peak spawning months.

The primary information produced by the proposed, multi-gear fishery-independent survey will be size-structured indices of abundance for bottomfishes and other fishery resources. The survey biomass indices produced from the expansion of stratified density estimates to the survey domain will give an index of absolute biomass of the bottomfish complex. This index will be used as a measure of abundance for individual species and the bottomfish complex as data to be predicted in either an integrated size-structured stock assessment model for individual species (Methot and Wentzel, 2013) or as a biomass dynamics-based stock assessment model for the Deep-7 complex (Brodziak et al., 2011). In particular, the survey biomass index will provide a measure of the scale of exploitable biomass, or biomass selected by the standardized fishing gear. This index will be assumed to be measured with observation error in the modeling process and will be formally treated as an input data point for fitting assessment model parameters. Prior distributions will be also developed for the survey catchability coefficients of individual species and the multi-species complex.

The proposed survey will also provide quantitative information on the state of the insular ecosystem of the main Hawaiian Islands, including biotic and abiotic processes. Survey results will be interpolated to produce maps of the spatial distribution of fishery resources. These maps can be used for marine spatial planning, including evaluation of the effectiveness of bottomfish restricted fishing areas as well as impacts of coastal development and offshore energy projects. With appropriate synchronous sampling, the survey could also provide fine-scale time series of data to describe regional physical oceanography and productivity, including sea surface temperatures and plankton densities. This data could be shared with other research efforts to foster the implementation of an ecosystem-based approach to managing ocean resources in the main Hawaiian Islands (Brodziak and Link, 2002).

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APPENDIX A— SeaBED AUV

The SeaBED Autonomous Underwater Vehicle (AUV) (Fig. 13) was designed and built by Woods Hole Oceanographic Institution (WHOI) as an autonomous, stable platform for slow-speed near-bottom surveys (Singh et al., 2004; Armstrong et al., 2006; Rivero-Calle et al., 2008; Williams et al., 2010). The capabilities of SeaBED have continued to increase such that it is now being used for species and habitat specific sampling of insular bottomfish and coral reef fish assemblages in the Pacific Islands Region as well as for routine sampling of groundfish stocks and their habitat along the U.S. west coast (Tolimieri et al., 2008; Clarke et al., 2009). SeaBED is approximately 2 m long and weighs nearly 200 kg. Unlike other more traditional AUVs, SeaBED is designed to autonomously follow the benthic terrain at a close, fixed altitude (typically 3–10 m) above the sea floor, providing a stable low-speed (0.5 kn) platform for the collection of high resolution optical data. The primary imaging system used in this study is a pair of forward-facing ultra low light Monochrome Navigator (Remote Ocean Systems, San Diego, CA) cameras, identical to that used on BotCam.

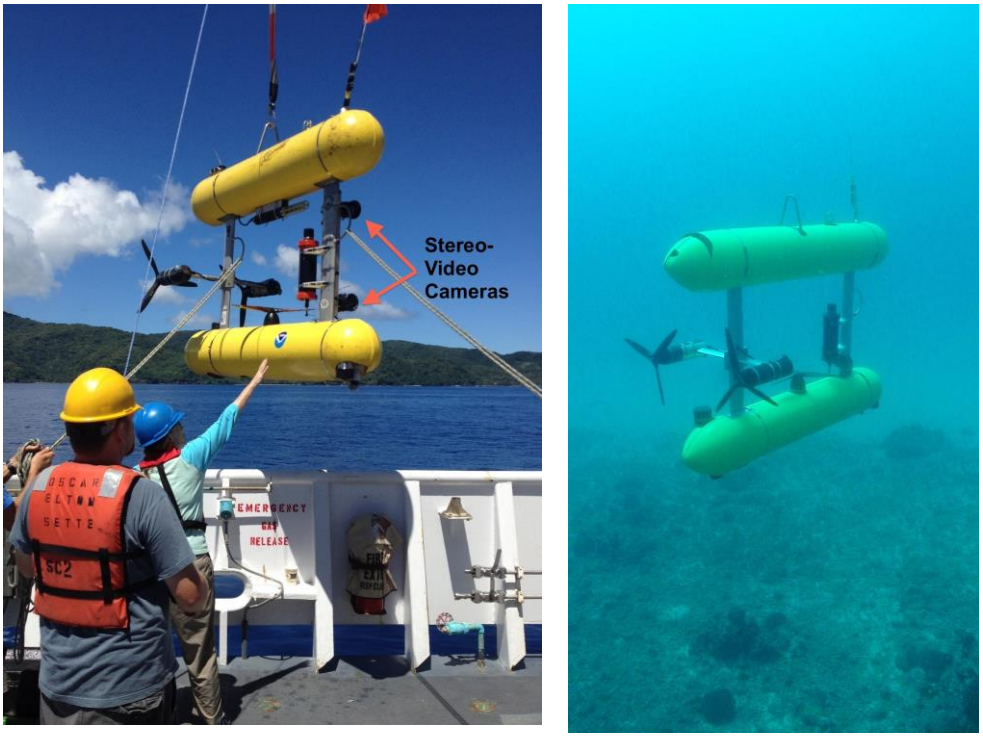

Figure 13.--The SeaBED AUV being recovered after a mission (left). Note the forward-facing stereo-video camera system mounted to the forward strut and indicated by the red arrows. The SeaBED AUV during operations along the south coast of Oahu, HI (right).

For this study, SeaBed generally completed 2 surveys per day, completing two 200-m transect lines within each of 2, adjacent PSUs during each survey. To date, the SeaBed has completed 37 surveys of which 26 recorded usable video data. However, analysis of the resultant stereo-video data has not yet been completed due to a lack of sufficient human video analysts and the need to develop robust methods for analyzing this transect style of stereo-video data that accurately

reflects bottomfish abundance. An initial investigation of a portion of the video data indicates that Deep-7 and other bottomfish species are observed. Cross-referencing the video time stamp of each fish observation with the time-stamped coordinate data from the AUV can be used to create maps of species distribution across the survey domain. To date, this has been done as a proof of concept using 3 AUV surveys conducted south of Maui in 2011 during mission SE1107 (Fig. 14).

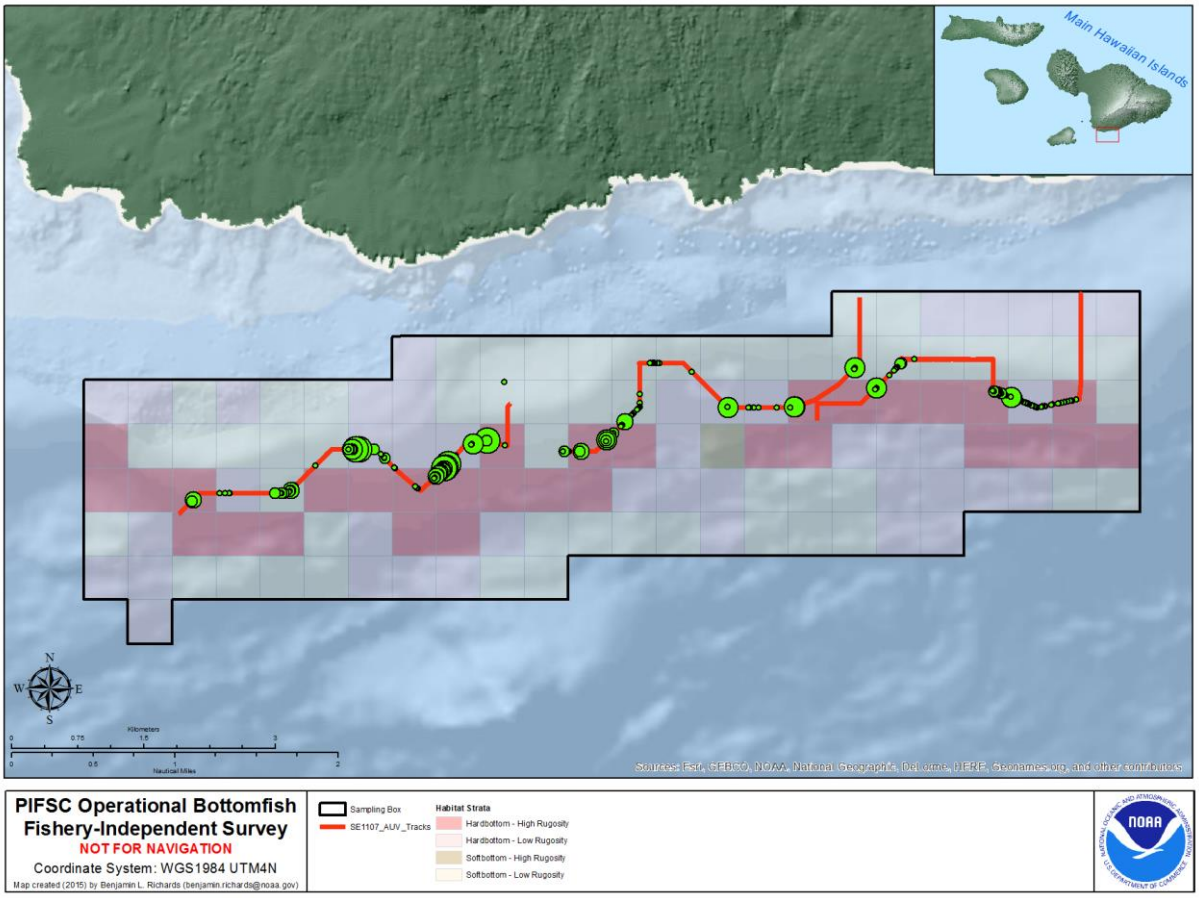

Figure 14.--A map showing fish observations from forward-looking stereo-video data collected during SeaBED AUV surveys. High resolution time and position for the AUV can be correlated with the time an individual fish was observed in the video data to calculate the position of each fish seen. Green circles denote a fish sighting while the diameter represents the number of individuals observed. While genus and species level observations are possible, do to a greater range from the camera, this level of classification is more difficult than with the BotCam system.

However, at this time, resources are not available to complete analysis of the full AUV video data set. Before analysis can continue, robust methods must be developed to ensure that abundance estimates derived from the AUV data are precise and accurate. Steps must be taken to ensure that fish following along with the AUV, such as *Seriola dumerili* as observed in our surveys, are not over-represented and further studies should be carried out to quantify behavioral interactions (i.e. avoidance or attraction) between the AUV and resident fish assemblages.
The stereo-video camera system on the SeaBED AUV is identical to that used in the BotCam and should have the same accuracy and precision when it comes to identifying and sizing Deep-7 individuals. SeaBED also has a high degree of positional precision and accuracy and can also be

used to survey across habitat gradients or to make repeated surveys over a feature of particular interest. While the SeaBED AUV performed well, resources were not available to analyze the video data streams and robust analysis methods for this style of transect video for bottomfish species have yet to be identified. While the MaxN method is appropriate for point surveys and ensures that individuals are not counted repeatedly, MaxN is likely not appropriate for transect surveys. Measures need to be adopted to minimize replicate counting as some species—specifically *Seriola dumerilii*—have been seen following or leading the AUV during surveys. While the forward motion of the AUV is slow and the AUV is not baited, is it still a large object moving through the water column and may attract or repel fishes. Behavioral reactions likely vary by species and need to be quantified. A study is currently underway in the Gulf of Mexico to quantify behavioral interactions between target species and survey gears including this AUV. The results of that study will have direct implications for our work.

While the SeaBED AUV can vary its depth during a survey, like research fishing and BotCam, it can sample only a single depth at a time. Hence, it is possible to miss fish that happen to be at a different depth, resulting in false negatives. SeaBED also has a high equipment cost and requires a team of 4 to 6 personnel to operate. This reduces the likelihood that multiple units will be fielded simultaneously. While the AUV can cover a large swath of sea floor during a single survey, the deployment, recovery, and servicing time required for each survey means that only 1 or 2 surveys covering 2–4 independent PSUs are possible per day.

APPENDIX B— EK60 Active Acoustics

EK60 data were collected using a Kongsberg Maritime AS Simrad EK60 echosounder system (Horten, Norway) on board the NOAA Ship *Oscar Elton Sette*. The Simrad split-beam, narrow-band transducers with 7° beam angles are mounted on a "transducer pod" underneath the hull of the ship and operate at 38, 70, and 120 kHz frequencies, facing vertically down. The depth of all transducers were approximately 5 m below surface, although the 70 kHz is positioned about 14 cm deeper than the 38 kHz transducer as the surface of the pod is slightly sloped aft relative to the horizontal. The exact depth of the transducers, however, depends on a variety of factors, such as ballast configuration, roll, and pitch, thus continuously changed throughout the surveys. Before each survey, the EK60 system was calibrated using a 38.1-mm diameter tungsten carbide sphere with 6% cobalt by the standard method (Foote et al., 1987). During EK60 data collection, all other sounders and activities that interfered with the bioacoustics signals were secured (e.g., fathometers, acoustic Doppler current profiler, needlegunning). Survey speed was approximately 4 kn.

Initially, data were collected using uniform 1,024 μs pulse-widths with 2, 1, and 0.5 kW power for the 38, 70, and 120 kHz channels, respectively. These settings were selected to provide maximum penetration achievable for the three frequencies and still stay within the recommended limits for the channels. However, during a software upgrade in 2013 from ER60-V2.2.1 to ER60-V2.4.2, the power settings originally selected were not available anymore and were changed to the new maximum settings of 2, 0.75, and 0.25 kW for the 38, 70, and 120 kHz frequencies, respectively. For all data collection, ping rate was set to maximum, resulting in approximately a pulse emitted at every 0.65 seconds. As initial data analyses proved that data from the 70 kHz frequency could be utilized best for separation of fish with gas-bladder from other organisms based on their acoustic properties, and this channel provided data down to over 700 m in depth, pulse-widths were shortened to 512 μs to double the vertical resolution during data acquisition. With these settings, the depth ranges of the 38, 70, and 120 kHz frequencies were approximately > 1,500 m, 600 m, and 250 m while the vertical resolution were kept at about 38 cm, depending on small variability in the speed of sound.

To obtain an equation representing the relationship of acoustic target strength (TS) to FL, simultaneous EK60 and optical observations (using baited BotCam, AUV, and ROV) and simultaneous EK60 and fishing operations were conducted. Length and species information obtained from the optical observations were compared to the TS readings and other acoustic descriptors such as aggregation density, size, shape, movement patterns, depth, distance from bottom, and bottom roughness. However, data from the AUV and ROV were not available at the time of data processing and analyzes, thus only video data from the BotCam could be used. The intermediate goal was to identify the Deep-7 as a group and separate them acoustically from all other species. Unfortunately, only one TS-FL pair could be obtained from BoCam with an additional 5 from fishing, so the general physoclist equation was used as first approximation (Foote, 1987).

Over the course of this study, three types of EK60 surveys were conducted. In 2011 and 2012, parallel transects were executed across all PSUs within a survey box (approx. 65 km total) (Fig. 2.a). These surveys were repeated at least every other day and night over the course of the survey mission to assess variability in the fish community. In 2013, when sampling methodology changed from stratification within survey boxes (SE1302, Fig. 2.a, Table 1), single surveys were conducted across 3-5 adjacent PSUs. During mission SE1306 (Table 1), six EK60 surveys (3 north-south, 3 east-west) were conducted within each PSU. Single-pass surveys were designed to achieve maximum coverage across the survey area and to quickly quantify the acoustic field within each PSU. After the first survey year, nighttime surveys were discontinued as daytime surveys detected significantly higher biomass and as all other gears were restricted to daytime operation. High variability between surveys necessitated the implementation of multi-pass surveys to determine the scale of temporal variability and determine the optimal number of repeat passes needed to adequately survey each PSU.

Initial data processing of the EK60 signals was performed using Myriax Echoview^{TM} software (Hobart, Tasmania). While all three frequencies were used in separating fish from smaller organisms, 38 kHz data and 70 kHz data were used for quantitative backscatter processing and analyses. During the earlier surveys, unavailability of an appropriately calibrated 70 kHz transducer required the use of the 38 kHz as the signal to noise ratio at 120 kHz was too low at 250–400 m depths, the deepest regions of bottomfish habitat. Prior to processing, noisy pings and bubble dropouts were removed and echograms were visually inspected to ensure high quality of data. The analysis domain was limited to 10 m below surface to the seafloor. However, EK60 cannot detect organisms effectively in close proximity of the bottom in rugose environments, creating an acoustics "deadzone". The depth of the deadzone depends on instrument settings, environment, and bottom topography with high rugosity. Seafloor depth was detected using Echoview's "best bottom candidate" line pick algorithm and manually adjusted to exclude all data due to bottom topography. Data were thresholded to only contain larger fish (approximately > 25 cm FL) , then regions with EK60 backscatter interpreted as bottomfish were classified as "bottomfish schools" and "bottomfish tracks" using Echoview's School Detection and Fish Tracking algorithms. Regions were selected using parameters developed from the simultaneous EK60 and complementary observations to specify parameters for these algorithms (Domokos, in prep). Regions of presumed bottomfish schools were identified from echograms of volume backscattering strength (S_v) thresholded to - 62 dB (dB re 1 m^{-1}) and put through a 3 × 3 pixel median then a 3×3 pixel dilution filter to help better define boundaries of fish schools. These regions were masked out of single target echograms to reduce erroneous single targets due to densely aggregated fish. Individual fish from loose aggregations or "strays" were identified from these single target echograms, thresholded to -42 dB (dB re 1 m^2).

TS associated with bottomfish were also exported from Echoview to estimate mean FL and weight of fish in the PSU using the general pysoclist TS-FL relation and mean Hawaii snapper values given by Froese and Pauly (2009). Once these values were obtained, they were used to estimate bottomfish densities within Echoview. EK60 backscatter from regions of presumed bottomfish, in the form of S_v, were integrated over 50 m horizontal bins over the water column and the resulting area backscattering coefficients (s_a in m^2m^{-2}) exported from Echoview. All subsequent data processing and analyses were carried out using MathWorks Matlab software (Natick, Massachusetts).

Bottomfish abundance was estimated by averaging S_a from each bin to arrive at a single value for an SSU. Values from bins affected by bottom topography were weighed to compensate for the reduction in area. Mean number of fish per m^2 within a grid cell was estimated by $\frac{\underline{S_a}}{\underline{\sigma_{bs}}}$(Simmonds and MacLennan, 2005) where $\underline{S_a}$is the mean s_a from the ESUs within the cell and $\underline{\sigma_{bs}}$is the mean backscattering cross section (in units of m^2) from the ESUs. To obtain an estimate of $\underline{\sigma_{bs}}$, mean TS from all bottomfish tracks were averaged in the linear domain and used in the equation $\sigma_{bs} = 10^{TS/10}$(Simmonds and MacLennan, 2005). The mean number of fish per m^2 for each PSU were multiplied by the area of PSUs (500 m^2) to obtain the estimated bottomfish abundance for that cell. Abundance estimates for m^2 from the S_a values were converted to weight using the mean lengths from TS and by the method described above (Froese and Pauly, 2009).

The hull mounted EK60 acoustic system was able to quickly provide a large amount of data on fish targets throughout the majority of the water column, over large spatial areas both day and night. However, presently the EK60 has low selectivity and the difficulty in distinguishing bottomfish from non-bottomfish species and in separating Deep-7 species from one another limit the utility of these data. More EK60 and simultaneous observations, especially from AUV cameras that seemed to be most cost-effective way to obtain information, will be necessary to improve current EK60 descriptors. Our current understanding of the echograms with focus on Deep-7 species is illustrated in Figure 15. While the information was obtained from simultaneous EK60 and other methods, images are selected to best illustrate the types of specific aggregations and loosely swimming fish echoes and are not necessarily from simultaneous observations.

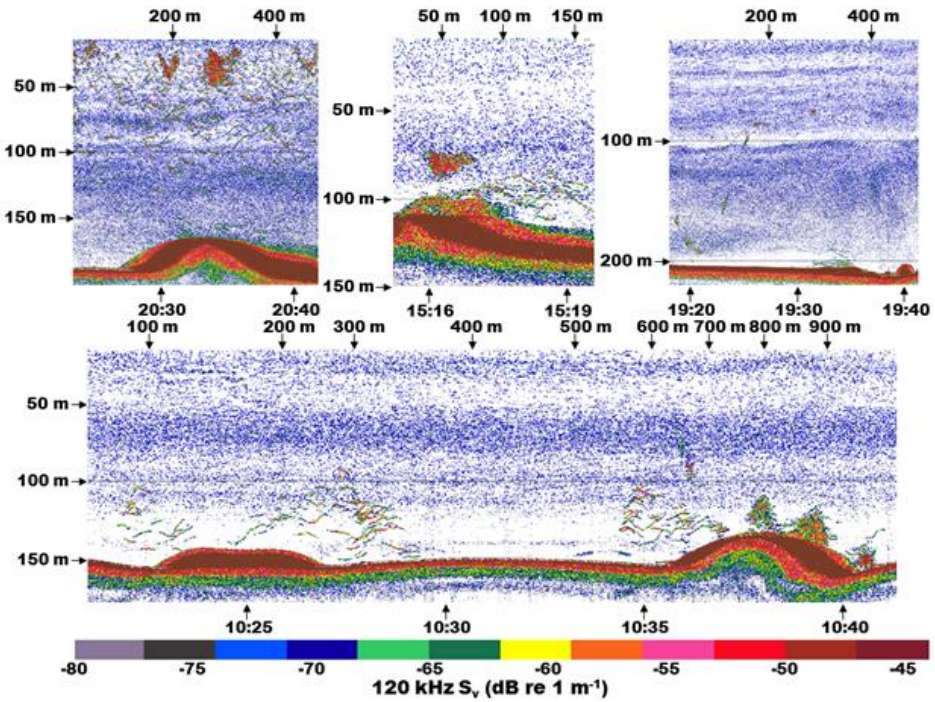

Figure 15.--Examples of bottomfish echograms at different depth ranges. Top left: near-surface and mid-water aggregations of Decapterus spp. in the evening; Top middle: fish aggregations at around 10-m depth, likely small Pristipomoides filamentosus, and/or Lutjanus kasmira, tightly aggregated on the bottom, with possibly some Mulloidichthys vanicolensis and/or Pristipomoides sieboldii intermixed. Above this aggregation are loosely spaced larger predatory P. filamentosus, Aphareus rutilans, and/or Seriola dumerili, and further up about 20 m off the bottom a tight aggregation of fish, possible Decapterus spp.; Top right: loose aggregations of Etelis carbunculus or maybe E. coruscans near the bottom, with a tight aggregation to their right, likely Antigonia spp.; Bottom: thick aggregations on the bottom are P. sieboldii, small P. filamentosus, L. kasmira, and possibly Naso unicornis, while loosely aggregated individuals extending over 50 m off the bottom are likely P. filamentosus, E. carbunculus, and/or S. dumerili. In this figure, species determination is based on

The use of EK60 for estimating biomass of demersal and semi-demersal fishes in other non-trawlable habitats is well established (Stanley et. al., 2000; Jones et. al., 2012; Ressler et. al., 2009; Rooper et. al., 2010; Rooper et. al., 2012). The EK60 has advantages over other gears as it is able to sample the majority of the water column simultaneously, avoiding the issue of the fish and the gear being in the same space horizontally, but in different locations vertically. EK60 can also sample the 100–400 m depth range utilized by Deep-7 bottomfish both day and night, without the artificial light that would currently be needed by the BotCam and AUV, and which would likely result in unknown behavioral interactions between the sampling gear and their targets. Surveying at 4 knots, EK60 methods can also cover a large spatial area in a short period of time, covering a larger portion of the geographic range of the stock than is possible with other methods in the same unit time. EK60 surveys can also provide simultaneous data on the distribution of fish as well as interactions between fish and their forage and can provide data at scales appropriate for effective ecosystem based management (Godø et al., 2014).

However, as currently implemented, the process of calibrating the EK60 transducers is time consuming. The current 9- to 36-hour calibration is untenable in an operational context. In addition, choppy waters due to commonly strong winds in the MHI can cause bubble dropout and cavitation noise, significantly reducing data quality. This is exacerbated by the position a of the EK60 transducers on the NOAA Ship *Oscar Elton Sette*, causing bubble sweep-down across the transducer faces.

The problem of estimating size distribution and species composition of acoustically observed targets has yet to be solved (McClatchie et al., 2000). This is a significant problem in the MHI region, where the Deep-7 assemblage often forms mixed schools both in terms of species and size class. The use of simultaneous EK60 data collection with video observations and fishing was used to develop EK60 descriptors for species or groups of species. However, due to limited resources, these data were not available at the time of data analyses, limiting the capability of EK60 to separate Deep-7 from other fish. This type of ground-truthing also does not adequately account for species observed acoustically, but not in optical or fishing surveys (false negative) and more robust methods for ground-truth should be developed. Our current inability to resolve species makes it difficult to quantitatively compare EK60 data to the highly selective species-specific, size-structured data produced by the other gear types. A distribution-specific (horizontal and vertical) species-size allocation derived from temporally similar optical and fishing methods for each PSU could be applied to EK60 data to scale the acoustically derived abundances to obtain more species specific information.

EK60 methods are also not able to sample the acoustic "deadzone" that exists for a certain distance above the bottom (Godø and Wespestad, 1993; Ona and Mitson, 1996). The height of this deadzone is determined at least in part by seafloor complexity, which is high in Hawaii and which is the preferred habitat of many of the Deep-7 species (Kelley et al., 2006; Misa et al., 2013). High spatial variability in seafloor complexity would require complex spatially varying models for this deadzone, which currently do not exist. Adjusting for bias due to the deadzone would require information on the proportion of species, individuals, and size classes resident within the deadzone compared to areas outside the deadzone. This information is also not currently available. In BotCam video footage, many the Deep-7 species are seen in close proximity (0-3 m) to the bottom and it is likely that hapu'upu'u, gindai, and ehu rarely leave the acoustic deadzone. The significance of the deadzone and the species-specific variation in its significance makes it more difficult to proportionally allocate the EK60 data by species using data from the other gear types.

At present, EK60 methods remain promising, especially if current efforts to include broadband acoustics move forward. Benoit-Bird et al. (2003) and Au and Benoit-Bird (2003) show that Deep-7 species do have species-specific signatures in broadband acoustic returns due to differences in gas bladder characteristics. Hence, the use of broadband acoustics should improve our ability to discriminate Deep-7 species from one another. Presently, EK60 may best be used to map the 3-dimensional spatiotemporal distribution of fish in the MHI, which can then be used to target deployment of more selective survey gears.

Availability of NOAA Technical Memorandum NMFS

Copies of this and other documents in the NOAA Technical Memorandum NMFS series issued by the Pacific Islands Fisheries Science Center are available online at the PIFSC Web site **http://www.pifsc.noaa.gov** in PDF format. In addition, this series and a wide range of other NOAA documents are available in various formats from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, U.S.A. [Tel: (703)-605-6000]; URL: **http://www.ntis.gov**. A fee may be charged.

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